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LOW COST TURBOPUMP STUDY

by

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA George C. Marshall Space Flight Center
Contract NAS 8-24859
Lee Jones, Project Manager

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FINAL REPORT

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CONTRACT NAS 8-24859

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FOREWORD

The study described herein, which was conducted by the Aerojet Liquid Rocket Company, Sacramento, California, was performed under Contract NAS 8-24859. It covers the period 30 June 1969 through 13 February 1970. The contract was sponsored by the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. It was administered under the technical direction of the Propulsion and Thermodynamics Division with Mr. Lee Jones as Project Manager.

ABSTRACT

A Low Cost Turbopumps Study was accomplished. It was aimed at developing a methodology for synthesizing lowest over-all cost turbopumps, which means that turbopump resulting in the lowest cost for a particular mission. This was done by examining the extent as well as manner that turbopump requirements affect over-all costs, investigating the technological level of cost-contributing operations, and evaluating the effect of this technological level upon over-all costs. The results then were utilized to evolve an optimal conceptual design of a selected turbopump configuration, along with preliminary planning for the development, production, and acceptance of the turbopump. The overwhelming conclusion from the study results is that a relaxation in requirements to reduce turbopump costs is not a fruitful way to decrease program costs. In effect, the potential exists for reducing turbopump program costs by as much as 40% (or 200-million dollars) through the appropriate tightening of design requirements to a degree that would permit acceptance test operations to be eliminated. Additionally large over-all program cost reductions could be accrued through this approach because of the cost sensitivity to engine performance (I_{sp}).

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I. SUMMARY

The Low Cost Turbopumps Study was aimed at developing a methodology for synthesizing lowest over-all cost turbopumps, which means that turbopump resulting in the lowest cost for a particular mission. This was accomplished by examining the extent as well as manner that turbopump requirements affect over-all costs, investigating the technological level of cost-contributing operations, and evaluating the effect of this technological level upon over-all costs. These results then were utilized to evolve an optimal conceptual design of a selected turbopump configuration, along with preliminary planning for the development, production, and acceptance of the turbopump. More specifically, the study was divided into the following three contractual tasks:

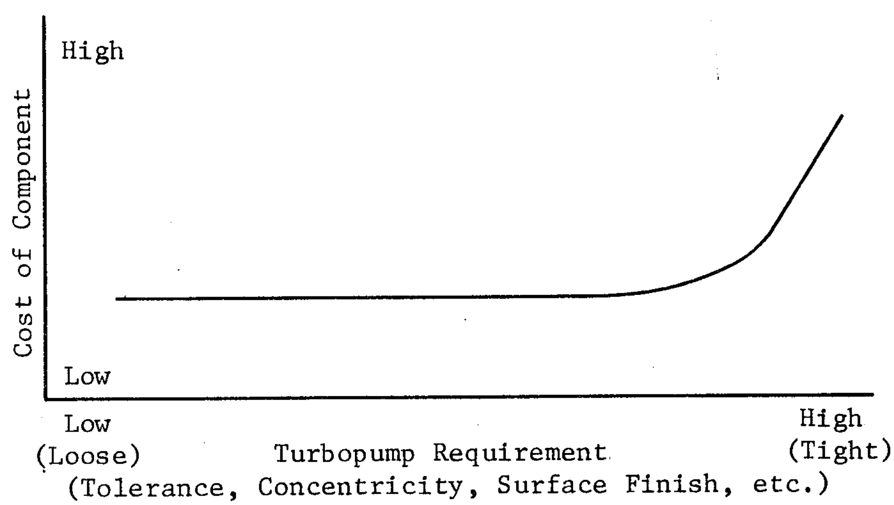
- Relationship of Turbopump Design Requirements to Over-All Costs
- Examinations of Cost-Contributing Operations
- Conceptual Design

Integral considerations for this study were the mission/vehicle/engine trade-offs, detailed subcomponent analyses, and subcomponent optimizations. The representative design case selected was a half-size version of an Advanced Multipurpose Large Launch Vehicle (AMLLV) with a 500,000 lb payload capability to low earth orbit. The contract imposed study constraints of a LOX/LH_2 propellant combination and a conventional packaging arrangement with a bell nozzle, gas generator, and gimbal mount. Chamber pressure and altitude thrust also were fixed at 1200 psia and 300,000 lb, respectively. This resulted in the following design characteristics being defined as those applicable to the base turbopump design:

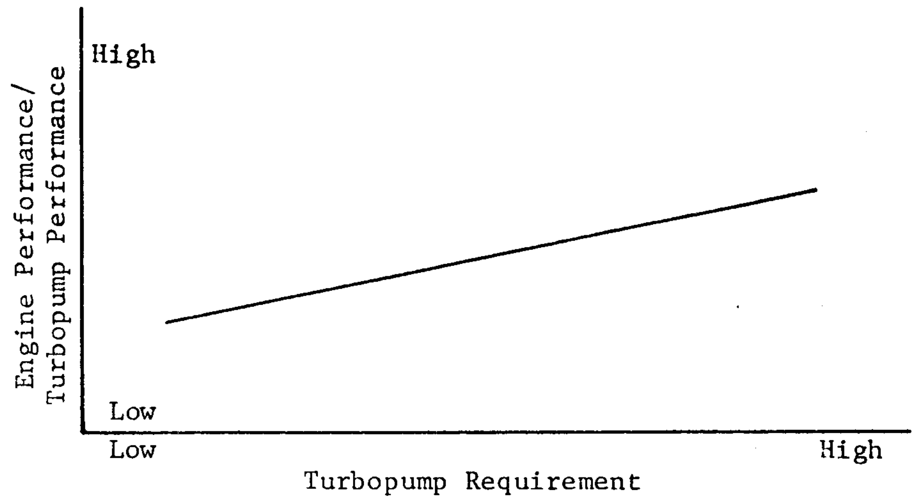
SYMBOL	CHARACTERISTIC	TURBOPUMP VALUES LH_2	TURBOPUMP VALUES LOX
ΔP	Pump Pressure Rise	1900 psi	1700 psi
$\dot{W}_p$	Pump Flow Rate	125 lb/sec	585 lb/sec
$P_{\tau i}$	Turbine Inlet Pressure	1190 psia	135 psia
PR	Turbine Pressure Ratio	7.5	3.4
T_{TI}	Turbine Inlet Temperature	1660°R	1250°R
$\dot{W}_T$	Turbine Flow Rate	20 lb/sec	20 lb/sec
NPSH	Pump Net Positive Suction Head	130 ft	25 ft

These basic requirements were used to generate reference conceptual designs for fuel and oxidizer turbopumps. Then, the operational costs for producing these turbopumps were determined. Next, the requirements were altered and changes in the cost-contributing operations and performance were noted. Following this, the changes in requirements and performance were related to the mission level costs. The methodology developed was tested by utilizing the study results as a basis for final conceptual designs as well as the formulation of development, production, and acceptance plans for these designs. It was shown that a turbopump program cost savings of 3% (or 10-million dollars) is available for a 17-million pound-to-orbit program. However, when the sensitivity of over-all program costs to performance is considered, these savings are nullified and, actually, increased costs could result.

Consequently, the overwhelming conclusion from this study is that the relaxation of requirements to reduce turbopump costs is not a fruitful way to decrease program costs. In effect, the potential exists for reducing turbopump program costs by as much as 40% (or 200-million dollars) through the appropriate tightening of design requirements to a degree that would permit acceptance test operations to be eliminated. Additionally large over-all program cost reductions could be accrued through this approach because of the cost sensitivity to engine performance (I_{sp}). This can best be visualized from the following qualitative curves:

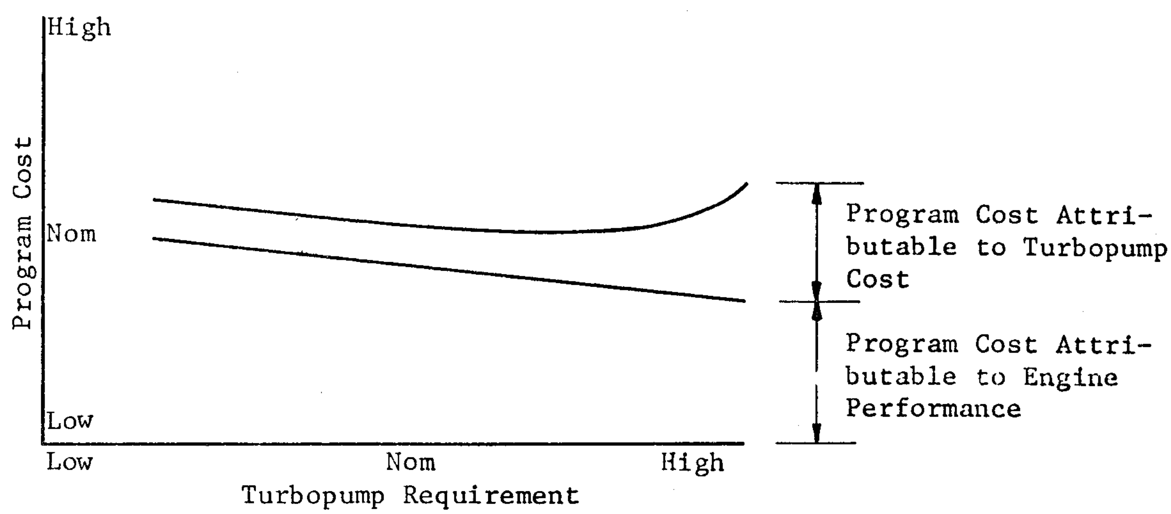


In the above curve, the general trend of the effect of turbopump requirements upon the cost of the turbopump components is illustrated. Most experienced engineering personnel will select a requirement that falls near the "knee" of the curve even when data is unavailable.



It can be seen from the above curve that turbopump performance is rather gradually affected by requirements in the reasonably attainable range.

When the above two trends are combined and superimposed, the following curve is evolved:



Note that a broad optimum results in terms of turbopump requirements. In highly performance-sensitive vehicles, such as the existing Space Shuttle concepts, the total program curve could become steeper than that for the highly performance-sensitive, single-stage to orbit MLLV. This would tend to drive the cost optimum turbopump toward even more rigid requirements.

The detailed supporting data for the above summarized trends is delineated in Section III of this report, along with other study results. The following is a brief index of the categorical study results and is provided for reader convenience.

RESULTS CATEGORY:	LOCATION IN TEXT:
Categorized Cost-Contributing Operations............	Section III,A,1.
Categorized Design Requirements.....................	Section III,A,2 and Appendix C.
Relationship Between Variations in Requirements and Cost-Contributing Operations....................	Sections III,A,2 and 3, Appendix C, and Figures No. 5, No. 6, and No. 11 through No. 66.
Description of Alternative Methods for Performing Cost-Contributing Operations and Recommendations for Additional Technology...........................	Sections III,B and IV,C, and Table XI
Relationship Between Turbopump Requirements and Cost..	Section III,A,4, Table X, and Appendixes K and L.
Optimal Turbopump Requirements and Design Criteria..	Section III,A,4 and Appendix L.
Low Over-All Cost Turbopump Conceptual Designs and Associated Development, Production, and Acceptance Plans.................................	Sections III,C,1 and 2, Table XII, and Appendix L.

II. INTRODUCTION

As the NASA proceeds into the post-Apollo era, costs are emerging as a dominant factor in selecting and promulgating alternative space goals. Consequently, the orientation of the technology planners has become the evolvement of a body of knowledge as well as a technical capability which will permit the attainment of meaningful goals at the lowest over-all costs. The subject Low Cost Turbopump Study is part of this new approach.

The traditional methodology applied to obtain the lowest over-all costs has been to generate a number of systems, all of which satisfy the specific technical requirements, and to select the lowest cost system or component from those generated. In the subject study, the objective was to develop a new or modified methodology which would permit synthesis of the lowest over-all cost system by including cost as a parameter at the outset. In this way, costs are considered as one of the elements of the system during the earliest apportionment of performance requirements. Additionally, any methodology developed for the turbopump portion of a system offers a high potential for applicability to the other elements of the engine/vehicle system.

The accomplishment of study objectives within contractual schedule and budgetary constraints necessitated that the scope of the effort be limited to a single representative application. Consequently, the following guidelines were mutually established.

CHARACTERISTIC	CONSTRAINT/VALUE	BASIS
Propellant Combination	LOX/LH_2	Contract
Engine Type	Conventional: Bell Nozzle, Gas Generator, and Gimbal Mount	Contract
Chamber Pressure	1200 psia	Contract
Altitude Thrust	300,000 lb	Contract
Application	Half-Size AMLLV; 500,000 lb Payload	Contract
Fuel Turbopump Base Configuration	Single-Stage Centrifugal Pump, Two-Stage Axial Turbine, Central-Propellant-Cooled Bearings	Contract Proposal
Oxidizer Turbopump Base Configuration	Single-Stage Centrifugal Pump, Single-Stage Axial Turbine, Central-Propellant-Cooled Bearings	Contract Proposal

The Multipurpose Large Launch Vehicle (MLLV) is similar in design to the Advanced Multipurpose Large Launch Vehicle (AMLLV) as defined by NASA Contract NAS2-4079. The MLLV was sized to provide a single-stage-to-orbit (100 nautical mile circular earth orbit) payload of approximately 500,000 lb. Greater payload capability (approaching 2-million lb) could be achieved by using injection stage modules and/or strap-on solid propulsion stages.

Only the core vehicle is utilized in the mission selected for this study, which is to place approximately 20-million lb of payload into orbit.

Recurring costs are most realistically expressed in terms of cost-per-unit while the maintenance of capability costs are best denoted in terms of cost-per-unit-of-time. Consequently, a program life and procurement rate were needed to permit an adjustment between the two and provide a basis for consistency. Two combinations of rate and life had to be investigated, but the individual values were left to the discretion of the Project Engineer (see Section III).

The results of Task I (Relationship of Turbopump Design Requirements to Over-All Costs) in this three-task study provided the basic data for synthesizing the lowest over-all cost design. These data included cost and performance information in terms of identical variable requirements as well as turbopump performance information in relationship to vehicle and mission costs.

Task II (Examination of Changes in Cost-Contributing Operations) provided cost data similar to that of task I but in terms of variable requirements for different technological levels of performing the significant (high cost) operations. These data showed at what level of requirements significant savings could be achieved by altering the method of designing, fabricating, or testing a component of the system.

Task III (Conceptual Design) served to demonstrate that the design methodology formulated from Tasks I and II actually could be applied to a realistic program while resulting in a turbopump cost savings reaching as high as 10-million dollars over the life of the program, but with negligible over-all program cost savings. However, the same methodology can be applied in a less conventional manner to provide a substantial reduction in over-all program costs by tightening rather than relaxing requirements.

III. TECHNICAL DISCUSSION

A. TASK I - RELATIONSHIP OF TURBOPUMP DESIGN REQUIREMENTS TO OVER-ALL COSTS

Task I was divided into the following four subtasks:

Ia - Identification and categorization of the cost-contributing operations

Ib - Identification and categorization of design requirements

Ic - Relationship of variations in design requirements to cost-contributing operations, turbopump/vehicle costs, and over-all costs

Id - Synthesis of design requirements to yield minimum over-all costs

The above subtask results, the basis of these results, the methodology applied to obtain them, and the limitations of these results are detailed in the ensuing discussions.

1. Subtask Ia - Cost-Contributing Operations

To obtain the necessary data for this subtask, a realistic conceptual design was essential to serve as the basis for selecting the operations and requirements. It was originally conceived that this would be an extensive conceptual design effort to generate configurations for both 1,000,000 lb and 300,000 lb thrust engines. However, budgetary and schedule limitations caused the higher thrust level design to be eliminated during contract negotiations and significantly reduced the effort devoted to generating the base designs at the 300,000 lbf level. Consequently, the configurations selected (see Figures No. 1 and No. 2) are non-optimum and result from a morphological evaluation as well as the necessary preliminary design calculations.

Many configurations were eliminated during the morphological evaluation based upon an objective consideration of fundamental turbopump characteristics. As an example, previous studies have shown the single turbopump to be unattractive because of the large difference in desired speeds for LOX and LH_2 pumps. The single geared oxidizer unit is unattractive at higher thrust levels because of its high development cost as well as the risk associated with gear drive systems. The twin-spool coaxial unit has an increased mechanical complexity which makes sealing more difficult and has a potential for causing a dramatic increase in development costs as well as risk.

Previous studies also have indicated that separate fuel and oxidizer turbopumps are desirable, particularly at the high thrust levels, because this arrangement permits independent optimum speed operation of the individual pumps to produce the required pressure rise. Normally, the LH_2 pump operates at approximately four to five times the speed of the LOX pumps (in units without a boost pump) because of NPSH requirements and propellant density differences. The best oxidizer pump selection generally has been a single-stage centrifugal pump with either a single or dual inlet, with the single inlet being the most common.

Fuel and oxidizer turbines can be arranged for either parallel or series flow. Studies have indicated that the parallel turbine arrangement is easier to control than the series system during engine throttling; however, throttling could be achieved with the series arrangement by utilizing proper by-pass valve sizing and control. The series turbine arrangement offers a significant reduction in turbine gas flow over the parallel system, but the ducting system is somewhat more complicated. Consequently, the candidate configurations shown on Figures No. 1 and No. 2 were selected as the bases for the Task I effort.

Having defined the basic configuration, it then was decided to concentrate the effort upon the 300,000 lbf case because maximum cost and design data were available for that class of machinery from previous development and operational programs. The resultant requirements for the base case turbopump designs are listed on Table I.

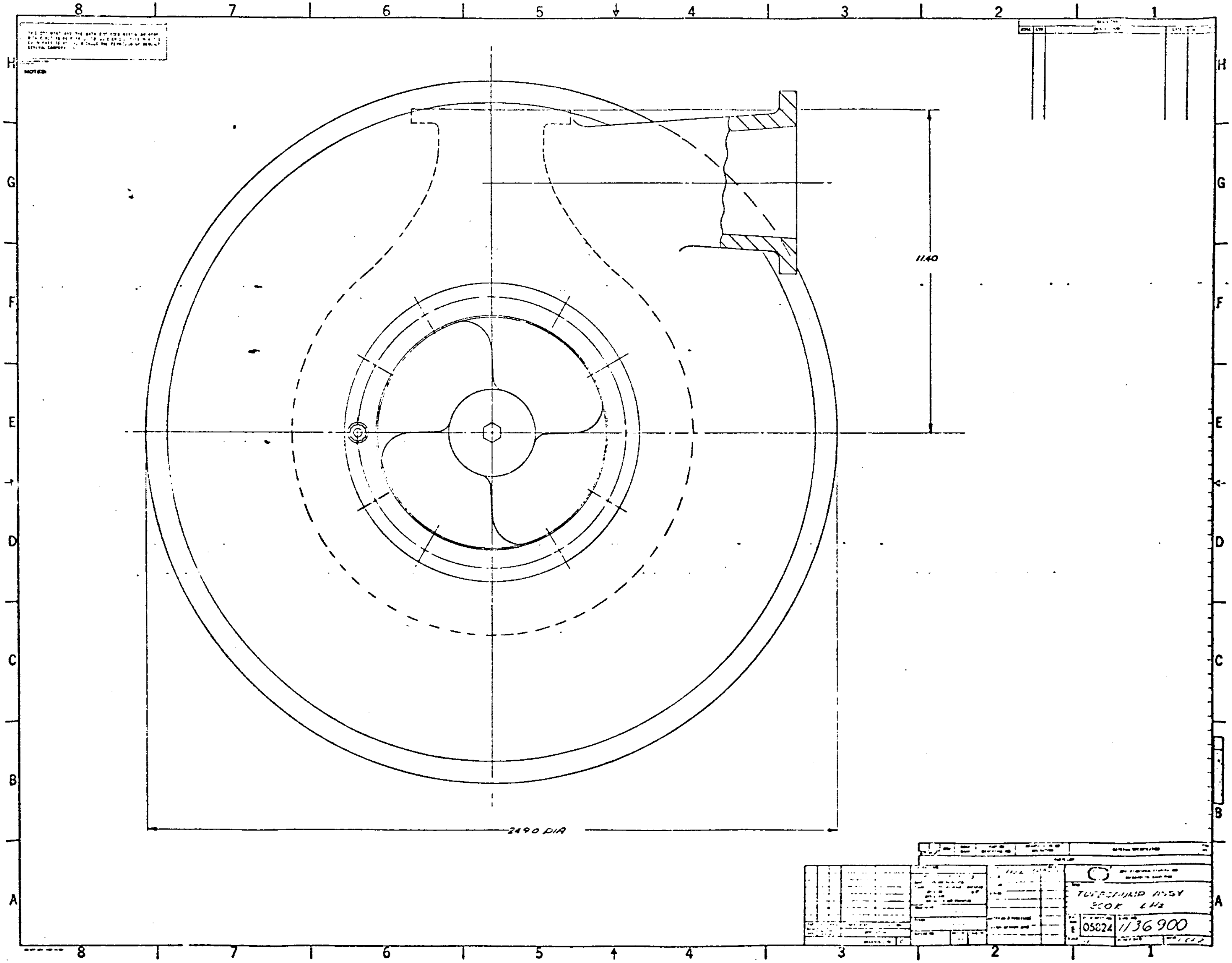


Figure 1. - LH_2 Turbopump Assembly (Sheet 1 of 2)

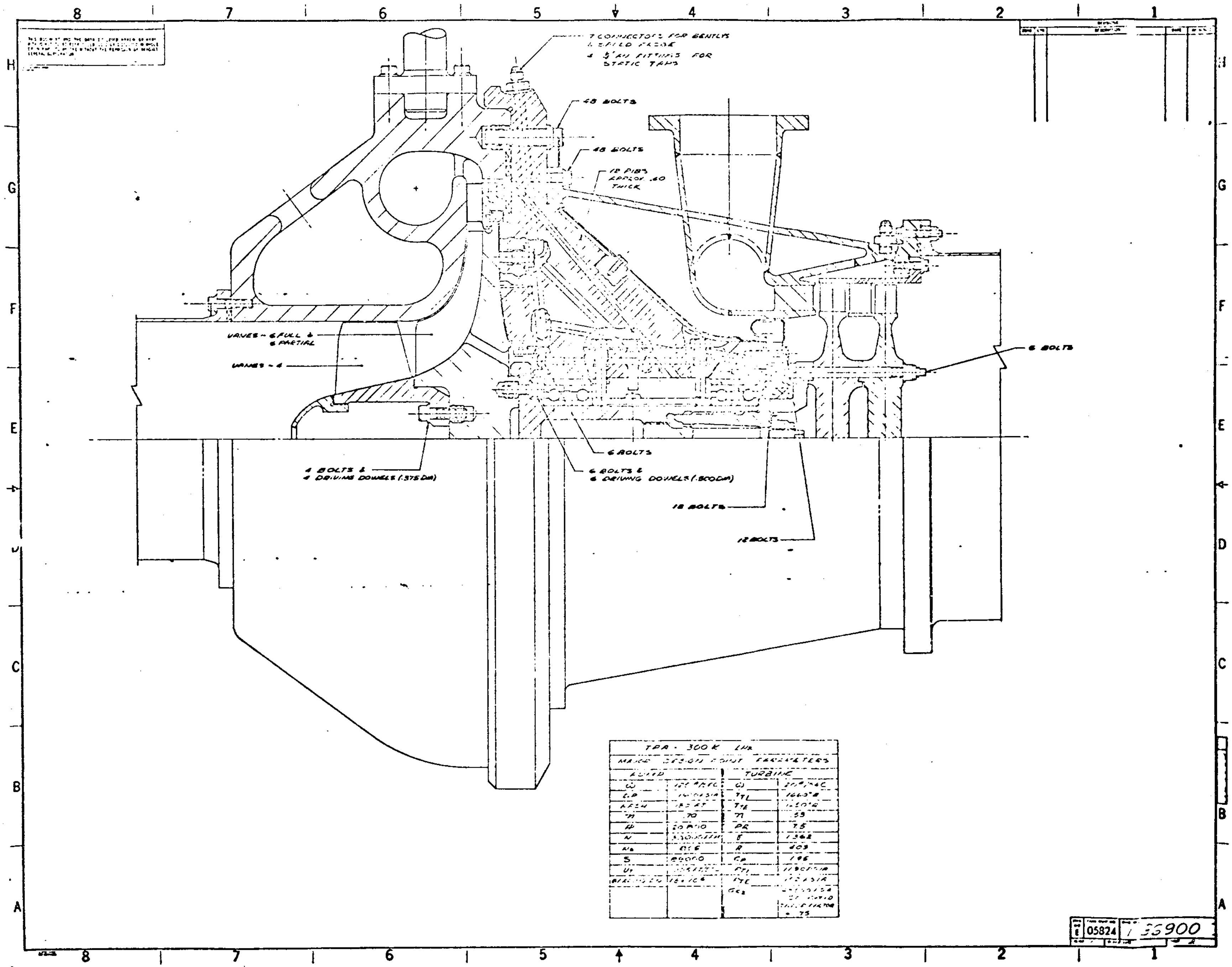


Figure 1. - LH_2 Turbopump Assembly (Sheet 2 of 2)

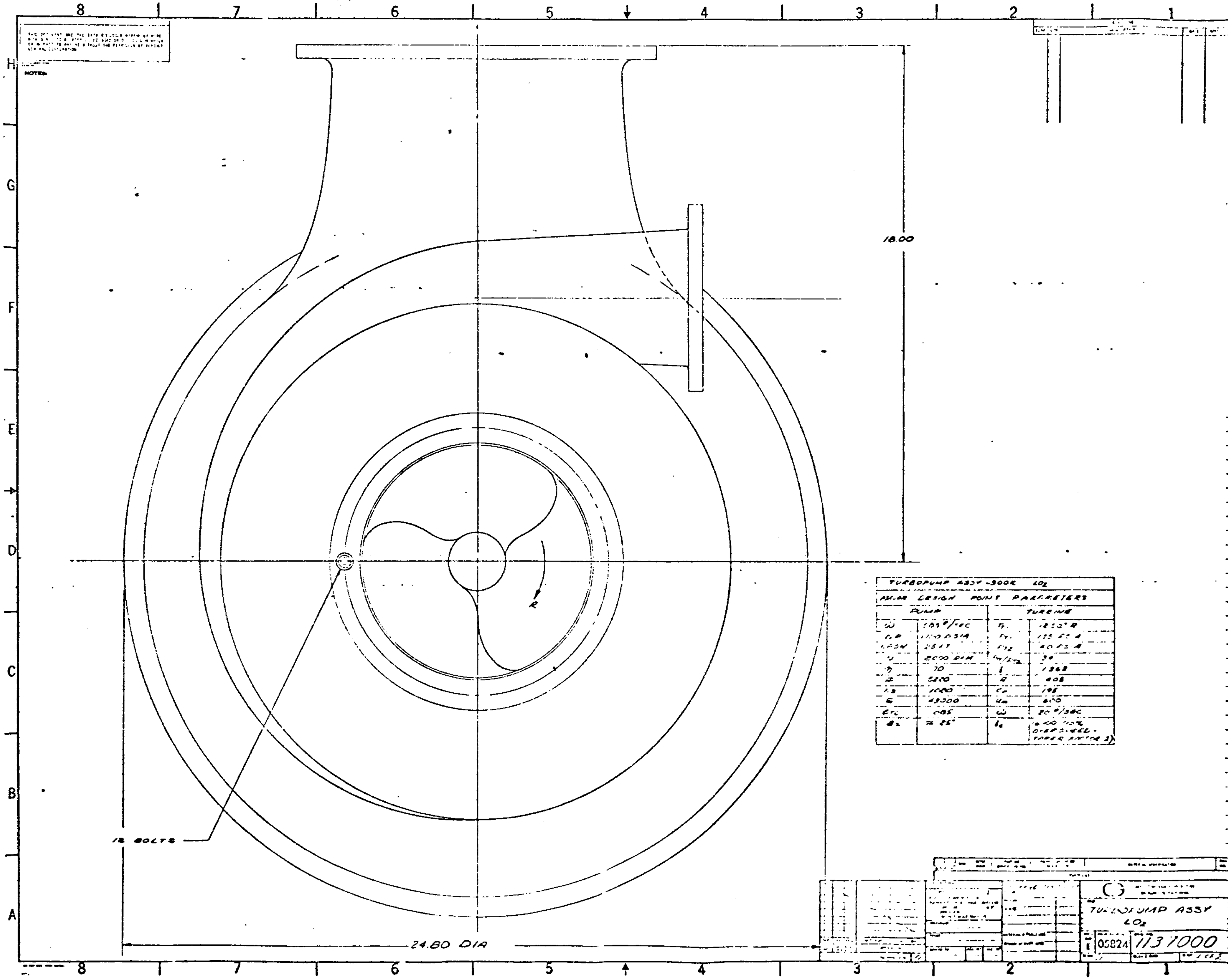


Figure 2. - LOX Turbopump Assembly (Sheet 1 of 2)

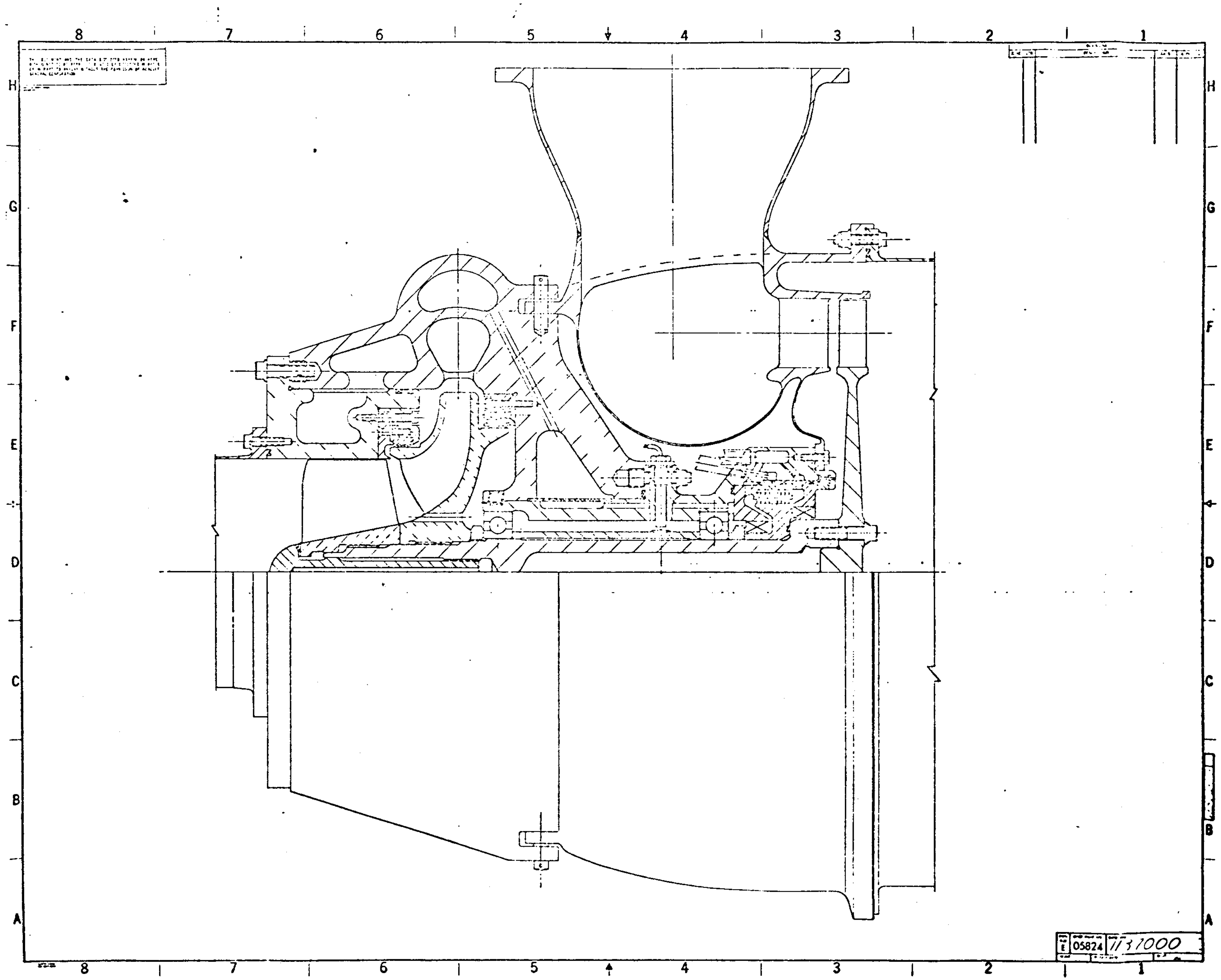


Figure 2. - LOX Turbopump Assembly (Sheet 2 of 2)

TABLE I. - BASE CASE REQUIREMENTS

Parameter	Requirement		
	Engine	Fuel Turbopump	Oxidizer Turbopump
Propellants	LOX/LH_2	LH_2	LOX
Application	MLLV (1/2 Size AMLLV)	-	-
Throttling	None	None	None
Startup	3 sec + Prechill	3 sec + Prechill	3 sec + Prechill
Duty Cycle	1 Start 300 sec	10 Starts/10 Hours	10 Starts/10 Hours
Reliability	0.97	0.998	0.998
Thrust	300,000 lb	-	-
Thrust Tolerance	± 3%	-	-
Chamber Pressure	1200 psia	-	-
Chamber Pressure Tolerance	± 1.5% (Control Value)	-	-
Specific Impulse	433 sec	-	-
Specific Impulse Tolerance	± 3 sec	-	-
Mixture Ratio	5:1	-	-
Mixture Ratio Tolerance	± 2.5%	-	-
Pump Pressure Rise	-	1900 psi	1700 psi
Pump Pressure Rise Tolerance	-	± 3%	± 3%
Pump Flow Rate	-	125 lb/sec	585 lb/sec
Pump Flow Rate Tolerance	-	Control Value	Control Value
NPSH	-	130 ft	25 ft
NPSH Tolerance	-	Minimum Value	Minimum Value
Turbine Inlet Pressure	-	1190 psia	135 psia
Turbine Pressure Ratio Tolerance	-	7.5	3.4
Turbine Pressure Ratio Tolerance	-	± 2%	± 2%
Turbine Flow Rate	-	20 lb/sec	20 lb/sec
Turbine Flow Rate Tolerance	-	± 5%	± 5%
Turbine Inlet Temperature	-	1660°R	1250°R
Turbine Inlet Temperature Tolerance	-	± 250°	± 180°
Static Seal Leakage	-	None	None
Dynamic Seal Leakage	-	0.05 lb/sec	0.05 lb/sec

Appendix A contains typical fuel turbopump preliminary design calculations and assumptions which illustrate the method utilized to size the components of the base case fuel turbopump shown on Figure No. 1. Similar simplified calculations were applied in sizing the base case oxidizer turbopump shown on Figure No. 2. The preliminary characteristic dimensions generated for both base cases are listed on Table II.

Next, the cost-contributing operations were identified and categorized in a number of variations. The final listing of these operations is included as Appendix B. This listing, as presented, represents a realistic level for investigating the cost of operations as they are influenced by changes in requirements. It is recognized that other categorical breakdowns are possible, but the listing offered is based upon the commonality of the same requirements variations affecting the cost of both design operations, primarily at the functional assembly level (i.e., pump, turbine, or power transmission), and fabrication operations at the subcomponent level (i.e., impeller and pump volute).

The general categorized listing of Appendix B does not have particular significance when viewed alone, but is highly useful as a checklist or guide in gathering data to be applied in relating the costs of performing operations for various requirements levels. However, this resultant listing reveals a significant weakness in the original proposed program. Each of the operations costs could be explicitly described and quantified in terms of man and machine hours based upon the particular set of detailed requirements assumed for the base case designs, but this would result in single point data not useful by itself in performing optimizations or tradeoff studies. Determination of the relationship between variations in requirements and cost-contributing operations required that the operations costs be quantified over a range of requirements. Identical techniques and manpower would be used for quantifying the base case operations costs and alternative requirements operations costs, but the original plan necessitated a redundant performance. This would have resulted in accomplishing the same effort twice as well as two separate tabulations of the data. Therefore, it was decided to defer quantification of the base case operations costs until quantified ranges of design requirements were available. Accordingly, this quantification was performed as part of Subtask Ic, where it is described.

2. Subtask Ib - Identification/Categorization of Design Requirements

Design requirements at the vehicle, engine, and turbopump levels generally can be segregated into the two broad categories of performance requirements and operational/mechanical requirements. At the subcomponent or part level, where the design requirements can be manipulated to affect design, fabrication, and test operations costs, virtually all design requirements must ultimately be mechanical or dimensional even though they can stem from performance requirements. Early recognition of this led to the

TABLE II. - PRELIMINARY CHARACTERISTIC DIMENSIONS

Characteristic Dimension	Value	
	Fuel Turbopump	LOX Turbopump
Impeller Inlet Diameter (Tip)	8.40	8.14
Impeller Inlet Diameter (Hub)	3.20	2.03
Impeller Discharge Diameter	14.75	12.90
Impeller Port Height	0.58	0.81
Base Circle Diameter	15.50	14.00
Diffuser Height	0.62	-
Diffuser Width	1.40	-
Volute Size (max section equiv dia)	2.37	3.50
Turbine Inlet Size (max section equiv dia)	3.65	9.94
Rotor Mean Diameter	9.95	17.20
1st Rotor Blade Height	0.92	2.48
2nd Rotor Blade Height	1.05	-
1st Rotor Chord	0.86	0.96
2nd Rotor Chord	0.78	-

realization that vehicle, engine, and turbopump level variations in design requirements would result in an overwhelming number of subcomponent alternatives because of the many possible ways of meeting a given set of the higher order design requirements. Therefore, it was decided to select only a base case set of vehicle, engine, and turbopump requirements from which to generate base case turbopump subcomponent requirements. Variations in subcomponent design requirements then could be selected and their impact upon both performance and cost parameters assessed. Next, the effects of the subcomponent requirements changes could be iterated at that level to synthesize realistic designs and an optimum set of turbopump level design requirements.

The following discussions describe the results of the effort to identify and categorize the design requirements and the variations selected for investigation.

a. Vehicle/Engine/Turbopump

The extensive categorized base case vehicle, engine, and turbopump design requirements selected are presented in Appendix C along with the basis for such selection. Requirements are segregated by the categories of performance, operational, and mechanical as well as by source (vehicle/engine or turbopump).

b. Turbopump Subcomponents

All of the turbopump subcomponent requirements are included under the mechanical category of Appendix C for the previously cited reasons. Although the alternative ranges of subcomponent requirements shown tend to reduce both the cost of manufacture and the hydraulic/aerodynamic performance, the size variations presented provide data at higher as well as lower NPSH, which reflects the higher and lower performance levels.

3. <u>Subtask Ic - Design Requirement Relationship to Cost Parameters, Turbopump/Vehicle Costs, and Over-All Costs</u>

a. Data

The following three major segments of information were needed to relate design requirement variations to over-all costs:

- How design requirements influence component costs
- How design requirements influence component performance
- How component performance influences over-all costs

Information concerning how design requirements influence component costs and performance was generated as part of the subject study program. The influence of component performance upon over-all costs was extracted from existing data developed by the Boeing Company under Contract NAS 2-5056 (Ref. 1). The ensuing discussions deal with the methodology utilized to generate or extract appropriate data, summarize the results, and describe the techniques used to relate the data. These data are presented by operation and requirement categories to facilitate comparison with the previously discussed operation and requirements listings.

(1) Cost versus Design Requirements

(a) Development Phase Design Operations

Aside from reliability and schedule requirements, the cost of design operations are relatively unaffected by design requirements. Additionally, no reasonable alternatives to the existing design methodology have presented themselves which will satisfy the mechanical reliability levels now needed to assure that essentially no flight or mission failures can occur during the life of the program. It is simply not possible to attain and demonstrate the required engine reliability by a test-fail-fix design/development philosophy within a reasonable (10 years or less) schedule. The implicit series flow of such a program, along with the known lead times for turbopump major subcomponents, makes it largely unfeasible to test even two alternative subcomponents to failure within the schedular restraint.

The failure mode analyses performed for the base case fuel and oxidizer turbopumps are summarized in Appendix D. They show that when part total duty cycle reliabilities are estimated and apportioned according to the method described below, the mean time to failure for many subcomponents is on the order of 100 hours to 1000 hours.

Step 1: All major turbopump subcomponents are listed.

Step 2: All modes wherein each subcomponent could fail are listed by part (a mode is defined as the part or assembly feature describing the failure).

Step 3: All mechanisms of failure are listed for each mode (a mechanism is defined as the property exhibiting the defect which precipitates the failure).

Step 4: All mechanisms of failure are rated by experienced turbopump specialists using scales ranging from A through D for design difficulty (A is well understood while D is poorly understood) and 1 through 4 for degree of control (1 is for easily controlled while 4 is difficult to control). The results then are averaged.

Step 5: The ratings are converted to a weighted rating defined as "relative failure potential" (RFP) based upon the matrix:

Rating		RFP
A-1	=	0.1
A-2, B-1	=	1.0
A-3, C-1	=	10.0
A-4, B-2, D-1	=	100.0
B-3, C-2	=	1000.0
B-4, D-2, C-3	=	10,000.0
C-4, D-3	=	100,000.0
D-4	=	1,000,000.0

Step 6: The relative failure potential is assumed equal to the number of failures per mission.

Step 7: The potential reliability of the subcomponents are calculated using the failure rate.

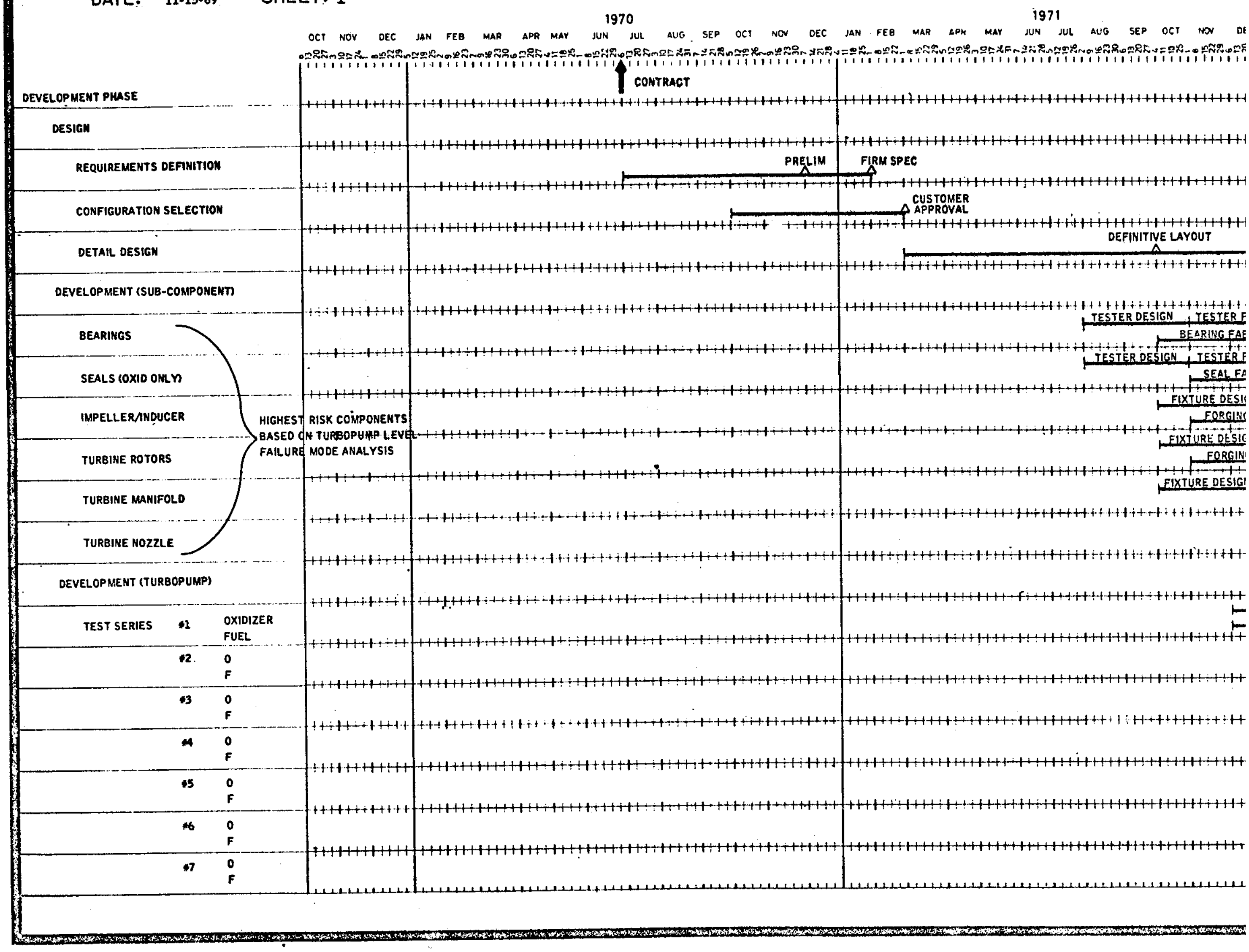
It is obviously that the turbopump reliability calculated by the above method can be biased by the amount of weight given the relative failure potential, but comparisons using the above scale factors have shown good agreement with historical Titan data.

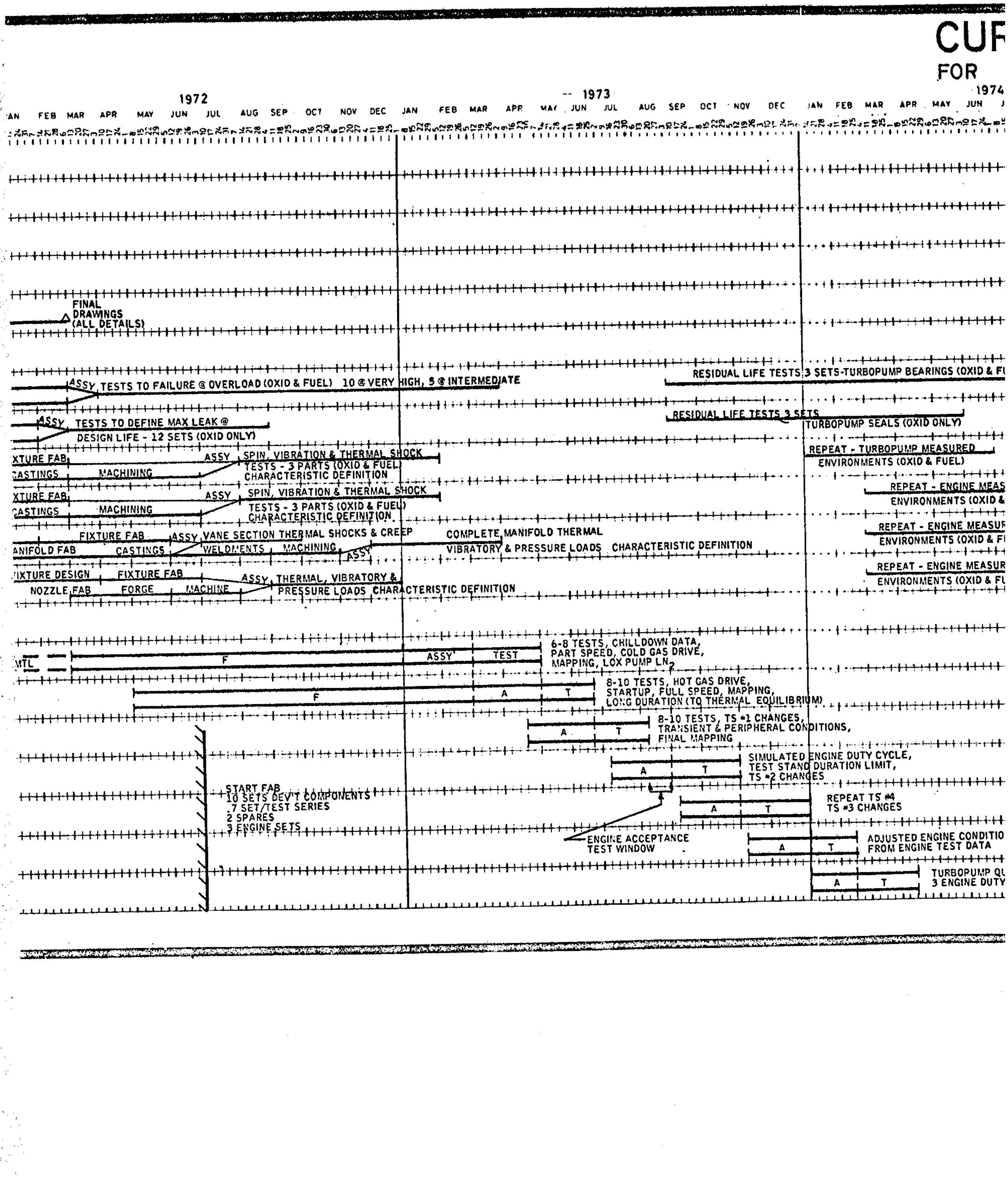
Current space goals require that all design techniques be utilized in conjunction with one another rather than selecting one which appears to offer the lowest cost of executing the design at a possibly lower turbopump reliability. In view of these factors and because the NASA interest does not extend to totally redundant and expendable weapons systems, no further attempt to relate requirements variations, other than schedular, to the cost of performing design operations was made.

The schedular variations investigated included the currently used "semiparallel" design and development effort as well as a proposed "full series" approach. The over-all schedular impact of these variations upon the base case and alternative program schedules are shown on Figures No. 3 and No. 4, respectively. Further amplification of the "full series" program follows.

Six subcategories make up the design task and each must be accomplished either during the proposal effort or in the contractual program.

PROJECT NO.
PROJECT TITLE: LOW COST TURBOPUMP - PRELIMINARY DEVELOPMENT, ACCEPTANCE & PRODUCTION PLANS
DATE: 11-15-69 SHEET: 1




CUF
FOR
1972
1973
1974
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
FINAL DRAWINGS (ALL DETAILS)
ASSY TESTS TO FAILURE @ OVERLOAD (OXID & FUEL) 10 @ VERY HIGH, 5 @ INTERMEDIATE
RESIDUAL LIFE TESTS 3 SETS-TURBOPUMP BEARINGS (OXID & FU
ASSY TESTS TO DEFINE MAX LEAK @ DESIGN LIFE - 12 SETS (OXID ONLY)
RESIDUAL LIFE TESTS 3 SETS TURBOPUMP SEALS (OXID ONLY)
XTURE FAB ASSY SPIN, VIBRATION & THERMAL SHOCK TESTS - 3 PARTS (OXID & FUEL) CHARACTERISTIC DEFINITION
CASTINGS MACHINING
REPEAT - TURBOPUMP MEASURED ENVIRONMENTS (OXID & FUEL)
REPEAT - ENGINE MEAS ENVIRONMENTS (OXID &
FIXTURE FAB ASSY VANE SECTION THERMAL SHOCKS & CREEP
ANIFOLD FAB CASTINGS WELDMENTS MACHINING ASSY
COMPLETE MANIFOLD THERMAL VIBRATORY & PRESSURE LOADS CHARACTERISTIC DEFINITION
REPEAT - ENGINE MEASUR ENVIRONMENTS (OXID & FU
FIXTURE DESIGN FIXTURE FAB
NOZZLE FAB FORGE MACHINE ASSY THERMAL, VIBRATORY & PRESSURE LOADS CHARACTERISTIC DEFINITION
MTL F ASSY TEST
6-8 TESTS, CHILLDOWN DATA, PART SPEED, COLD GAS DRIVE, MAPPING, LOX PUMP LN2
F A T
8-10 TESTS, HOT GAS DRIVE, STARTUP, FULL SPEED, MAPPING, LONG DURATION (TO THERMAL EQUILIBRIUM)
A T
8-10 TESTS, TS #1 CHANGES, TRANSIENT & PERIPHERAL CONDITIONS, FINAL MAPPING
A T
SIMULATED ENGINE DUTY CYCLE, TEST STAND DURATION LIMIT, TS #2 CHANGES
START FAB
10 SETS DEV'T COMPONENTS
7 SET/TEST SERIES
2 SPARES
3 ENGINE SETS
A T
REPEAT TS #4
TS #3 CHANGES
ENGINE ACCEPTANCE TEST WINDOW
A T
ADJUSTED ENGINE CONDITIO FROM ENGINE TEST DATA
A T
TURBOPUMP QU
3 ENGINE DUTY

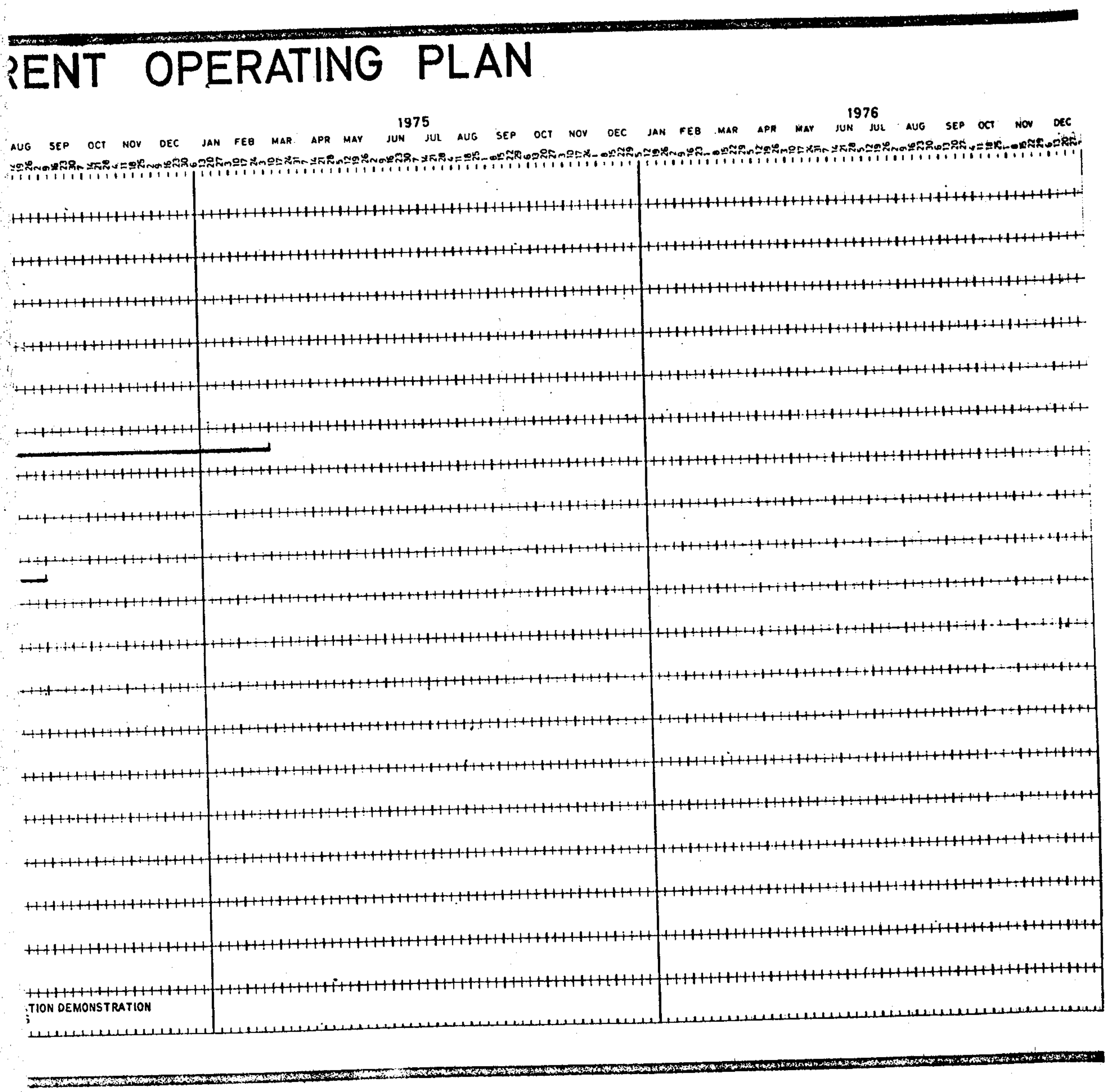


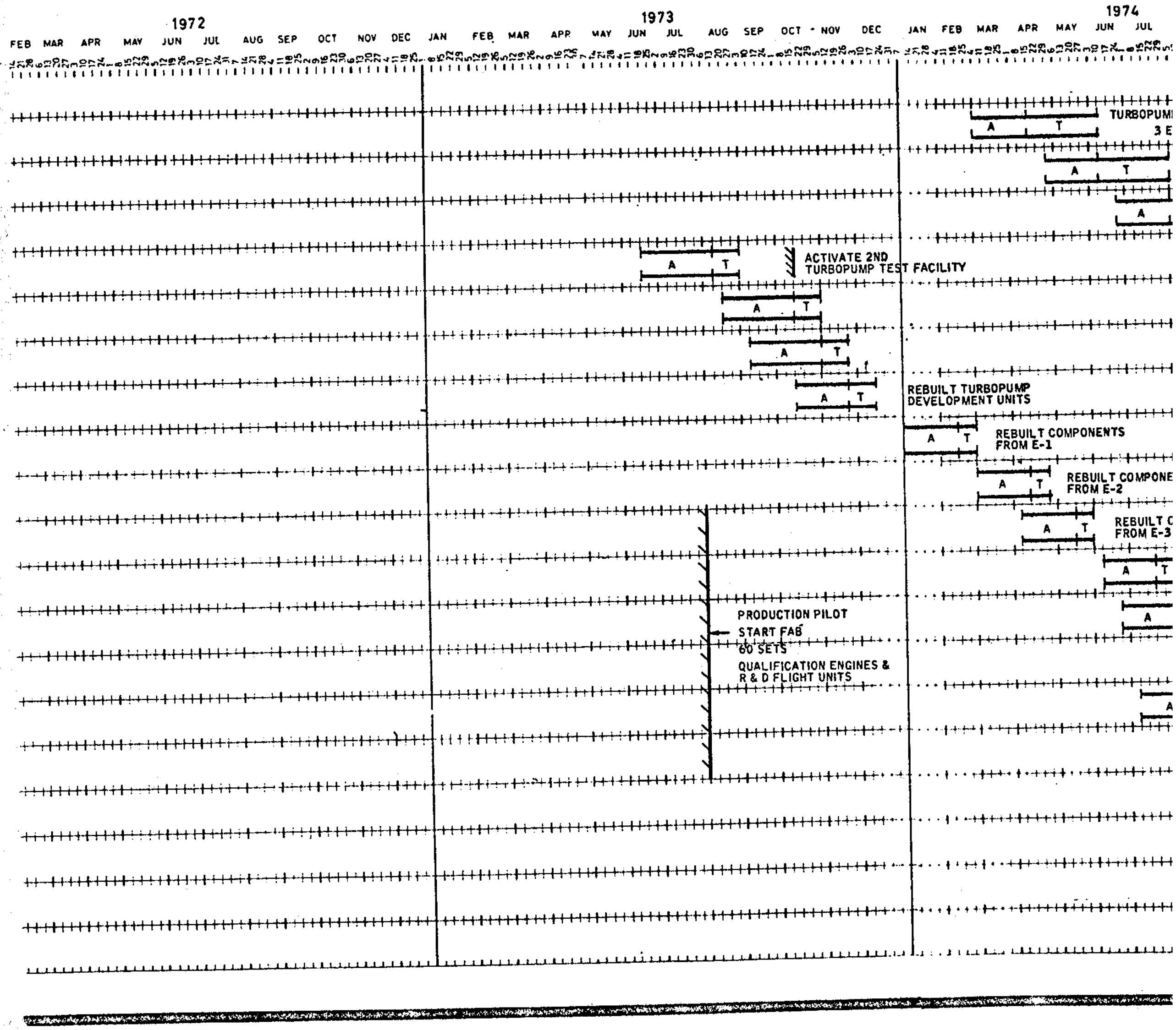
Figure 3. - Current Operating Plan, Semiparallel Approach (Sheet 1 of 2)

PROJECT NO.
PROJECT TITLE: LOW COST TURBOPUMP - PRELIMINARY DEVELOPMENT, ACCEPTANCE & PRODUCTION PLAN
DATE: 11-15-69 SHEET: 2

	1970														1971											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DEVELOPMENT (TURBOPUMP CONT'D)																											
TEST SERIES #8 O F																											
#9 O F																											
#10 O F																											
ACCEPTANCE TEST FOR R & D ENGINE #1 O F																											
#2 O F																											
#3 O F																											
#4 O F																											
#5 O F																											
#6 O F																											
#7 O F																											
#8 O F																											
#9 O F																											
ACCEPTANCE TEST FOR R & D FLIGHT ENGINES (1ST FLIGHT) O F																											
(2ND FLIGHT) O F																											
PRODUCTION PHASE																											
TWO LAUNCHES PER YEAR BASED ON MLLV COST STUDY RESULTS (BOEING DOCUMENT D5-13463-6)																											

CURF

FOR


1972
FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1973
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1974
JAN FEB MAR APR MAY JUN JUL
TURBOPUM
3 E
ACTIVATE 2ND TURBOPUMP TEST FACILITY
REBUILT TURBOPUMP DEVELOPMENT UNITS
REBUILT COMPONENTS FROM E-1
REBUILT COMPONE FROM E-2
REBUILT C FROM E-3
PRODUCTION PILOT
START FAB
60 SETS
QUALIFICATION ENGINES & R & D FLIGHT UNITS

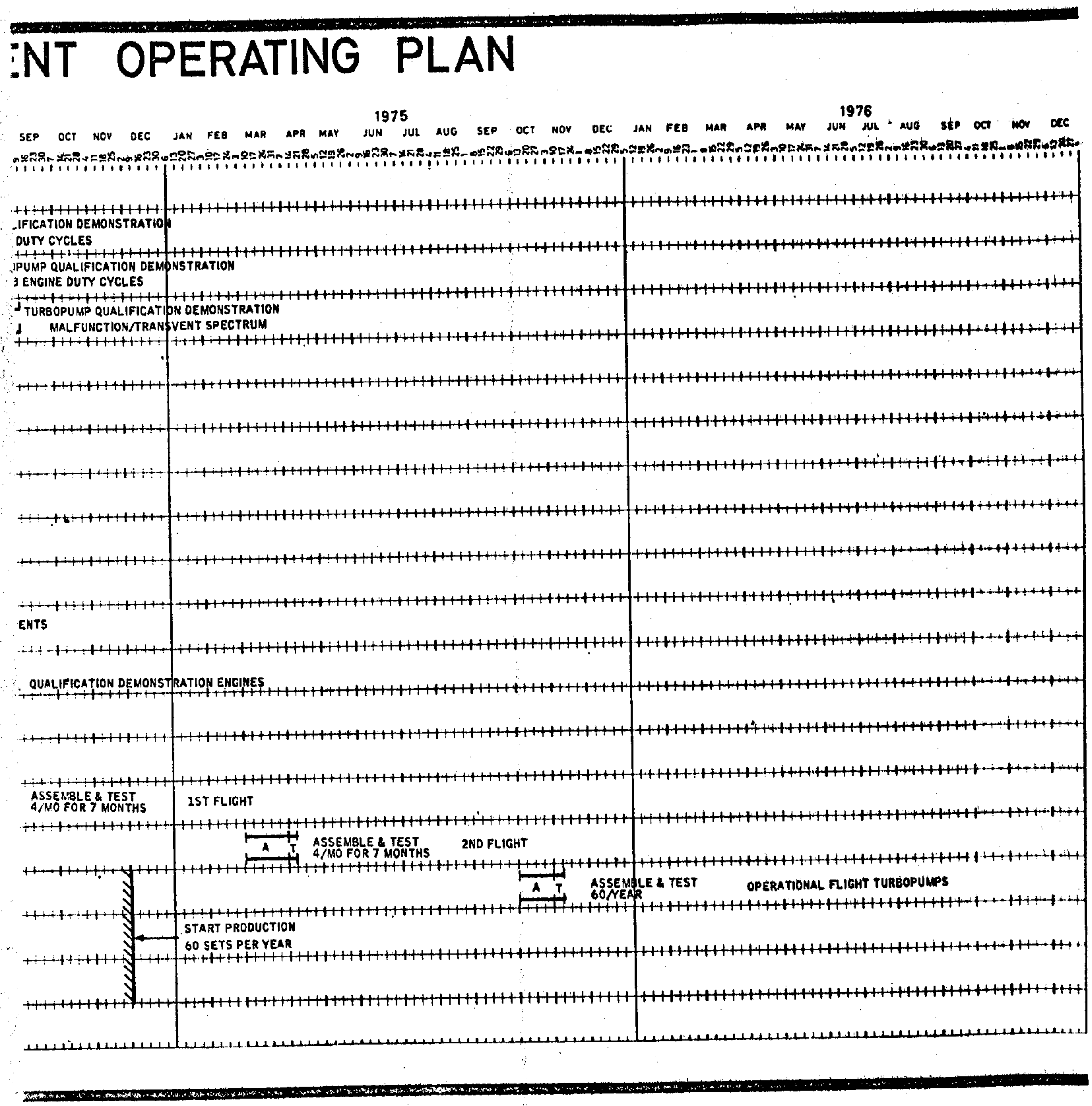
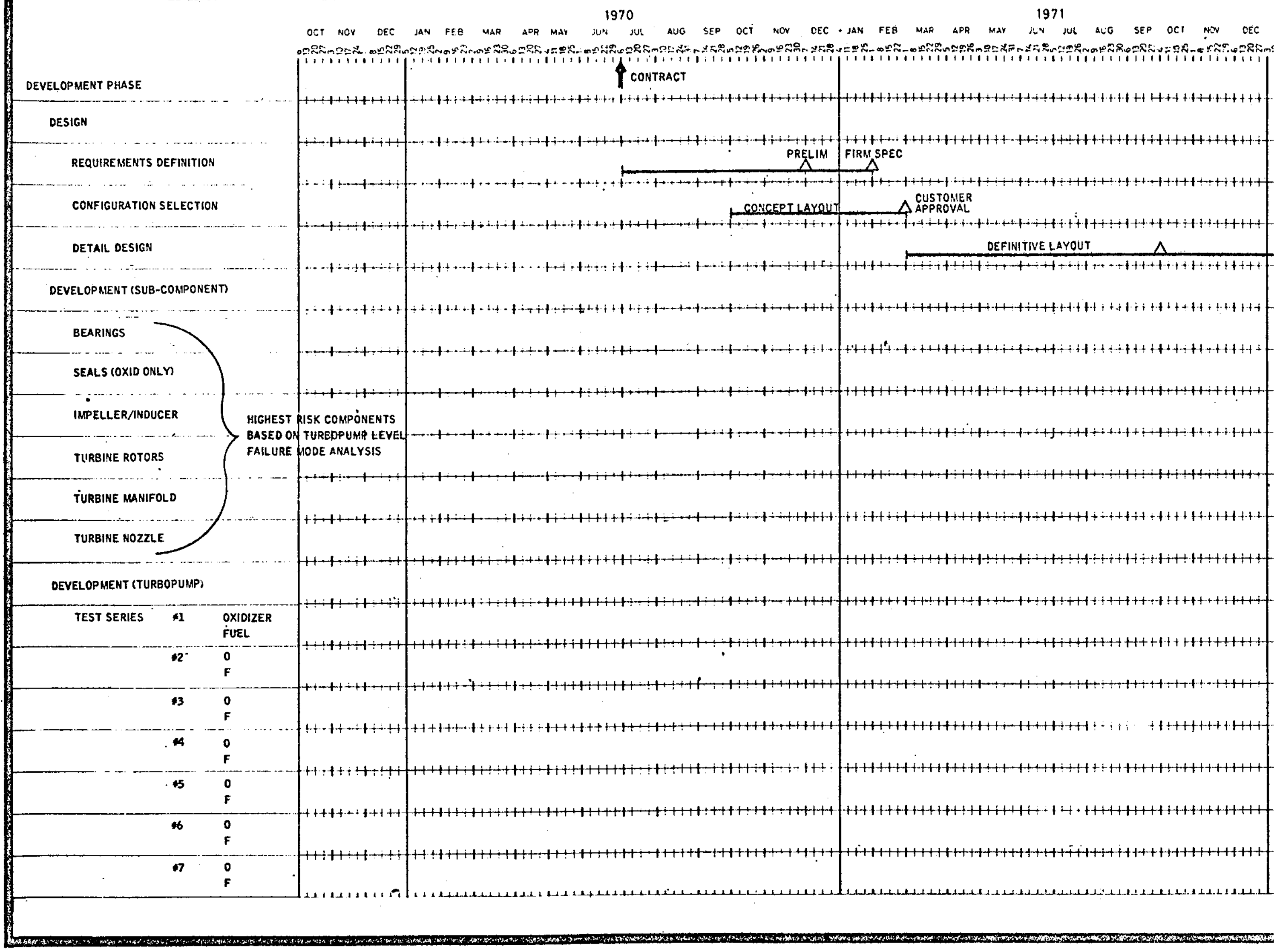
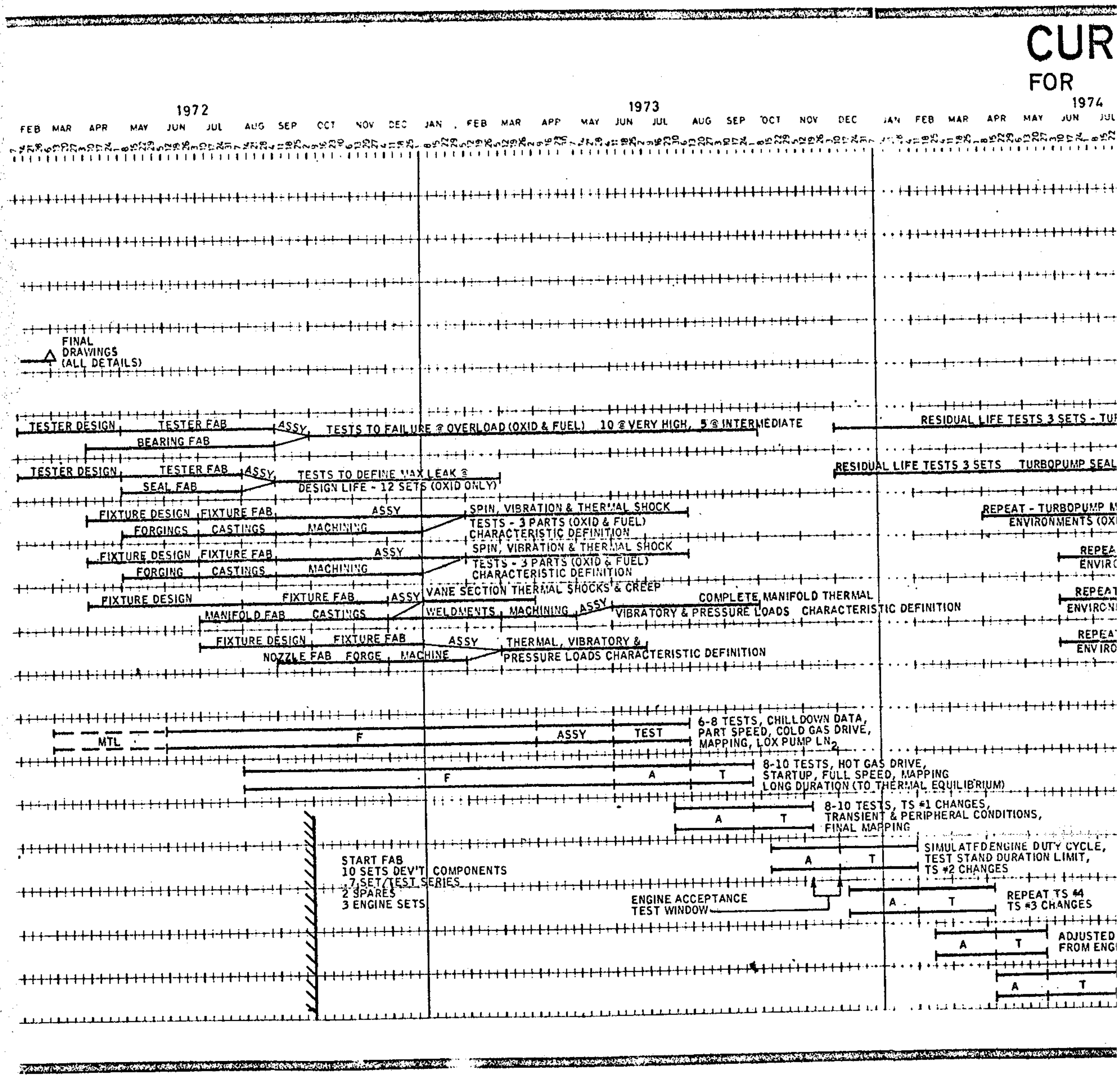


Figure 3. - Current Operating Plan, Semiparallel Approach (Sheet 2 of 2)

PROJECT NO.
PROJECT TITLE LOW COST TURBOPUMP - PRELIMINARY DEVELOPMENT, ACCEPTANCE & PRODUCTION PLANS (FULL SERIES ALTERNATIVE)
DATE 11-15-69 SHEET: 1





CUR
FOR
1972
1973
1974
FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
JAN FEB MAR APR MAY JUN JUL
FINAL DRAWINGS (ALL DETAILS)
TESTER DESIGN
TESTER FAB
ASSY
TESTS TO FAILURE @ OVERLOAD (OXID & FUEL) 10 @ VERY HIGH, 5 @ INTERMEDIATE
BEARING FAB
RESIDUAL LIFE TESTS 3 SETS - TU
TESTER DESIGN
TESTER FAB
ASSY
TESTS TO DEFINE MAX LEAK @ DESIGN LIFE - 12 SETS (OXID ONLY)
SEAL FAB
RESIDUAL LIFE TESTS 3 SETS TURBOPUMP SEAL
FIXTURE DESIGN
FIXTURE FAB
ASSY
SPIN, VIBRATION & THERMAL SHOCK TESTS - 3 PARTS (OXID & FUEL) CHARACTERISTIC DEFINITION
FORGINGS
CASTINGS
MACHINING
REPEAT - TURBOPUMP M ENVIRONMENTS (OX
FIXTURE DESIGN
FIXTURE FAB
ASSY
SPIN, VIBRATION & THERMAL SHOCK TESTS - 3 PARTS (OXID & FUEL) CHARACTERISTIC DEFINITION
FORGING
CASTINGS
MACHINING
REPEA ENVIR
VANE SECTION THERMAL SHOCKS & CREEP
FIXTURE DESIGN
FIXTURE FAB
ASSY
COMPLETE MANIFOLD THERMAL
MANIFOLD FAB
CASTINGS
WELDMENTS
MACHINING
ASSY
VIBRATORY & PRESSURE LOADS CHARACTERISTIC DEFINITION
REPEAT ENVIRON
FIXTURE DESIGN
FIXTURE FAB
ASSY
THERMAL, VIBRATORY & PRESSURE LOADS CHARACTERISTIC DEFINITION
NOZZLE FAB
FORGE
MACHINE
REPEA ENVIRO
MTL
F
ASSY
TEST
6-8 TESTS, CHILLDOWN DATA, PART SPEED, COLD GAS DRIVE, MAPPING, LOX PUMP LN_2
F
A
T
8-10 TESTS, HOT GAS DRIVE, STARTUP, FULL SPEED, MAPPING LONG DURATION (TO THERMAL EQUILIBRIUM)
A
T
8-10 TESTS, TS #1 CHANGES, TRANSIENT & PERIPHERAL CONDITIONS, FINAL MAPPING
START FAB 10 SETS DEV'T COMPONENTS 7 SET/TEST SERIES 2 SPARES 3 ENGINE SETS
A
T
SIMULATED ENGINE DUTY CYCLE, TEST STAND DURATION LIMIT, TS #2 CHANGES
ENGINE ACCEPTANCE TEST WINDOW
A
T
REPEAT TS #4 TS #3 CHANGES
A
T
ADJUSTED FROM ENG
A
T

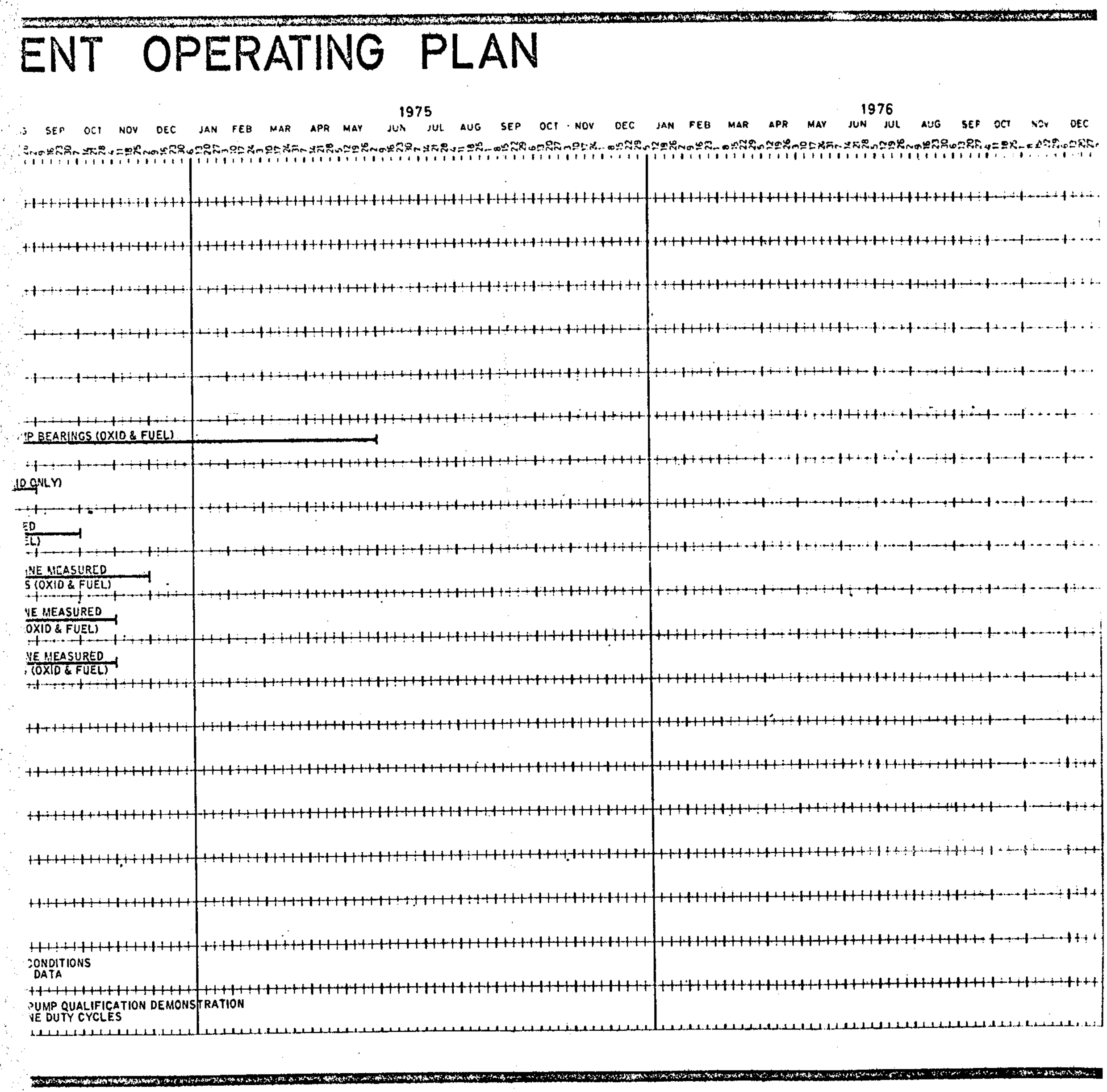


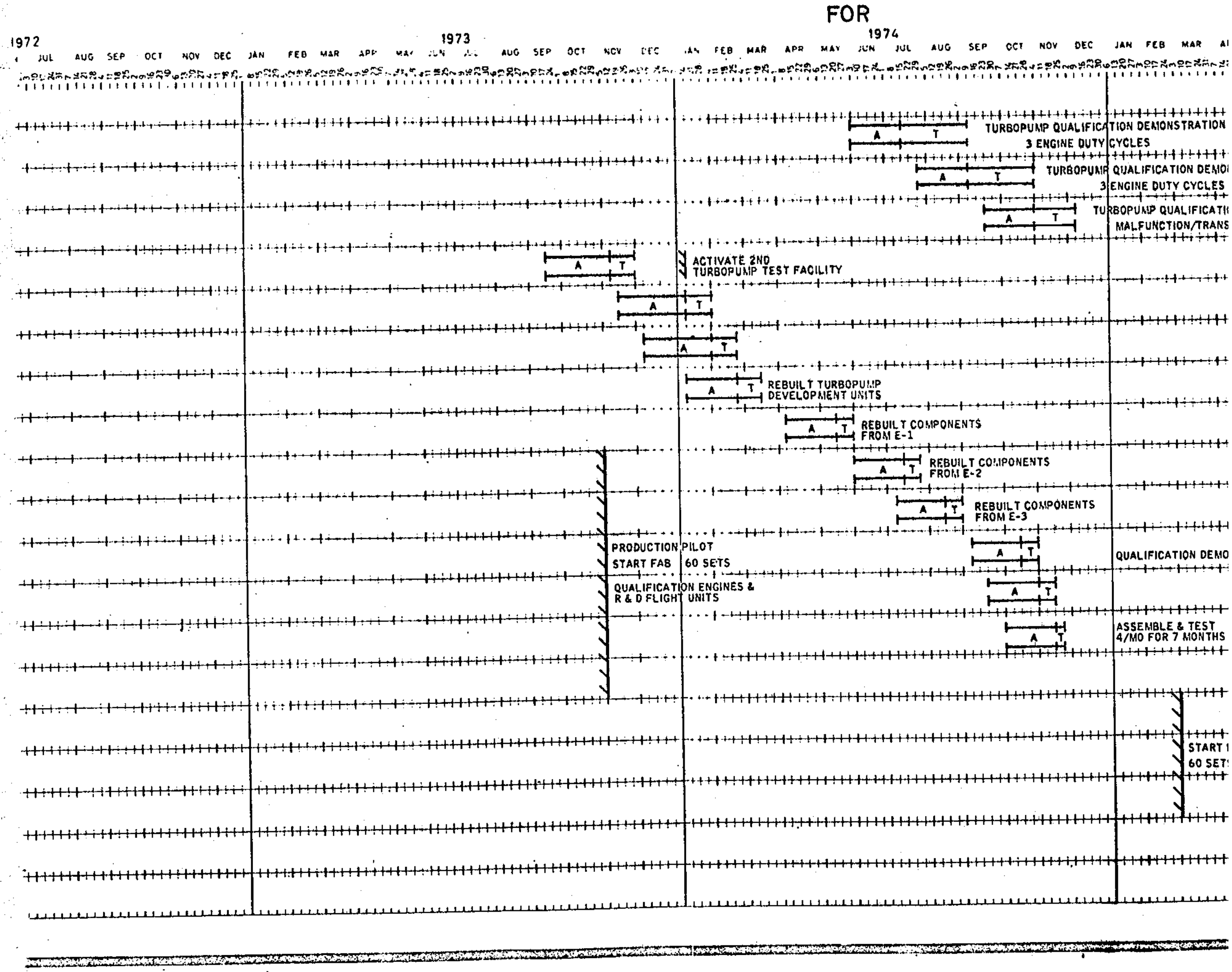
Figure 4. - Current Operating Plan, Full Series Approach (Sheet 1 of 2)

PROJECT NO.
PROJECT TITLE LOW COST TURBOPUMP - PRELIMINARY DEVELOPMENT, ACCEPTANCE & PRODUCTION PLAN (FULL SERIES ALTERNATIVE)
DATE: 11-15-69
SHEET: 2

	1970	1971	
	OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC	JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC	JAN FEB MAR APR MA
DEVELOPMENT (TURBOPUMP CONT'D)			
TEST SERIES #8 O F			
#9 O F			
#10 O F			
ACCEPTANCE TEST FOR R & D ENGINE #1 O F			
#2 O F			
#3 O F			
#4 O F			
#5 O F			
#6 O F			
#7 O F			
#8 O F			
#9 O F			
ACCEPTANCE TEST FOR R & D FLIGHT ENGINES (1ST FLIGHT) O F			
(2ND FLIGHT) O F			
PRODUCTION PHASE O F			
TWO LAUNCHES PER YEAR BASED ON MLLV COST STUDY RESULTS (BOEING DOCUMENT D5-13463-6)			

CURRENT OPERATI

FOR



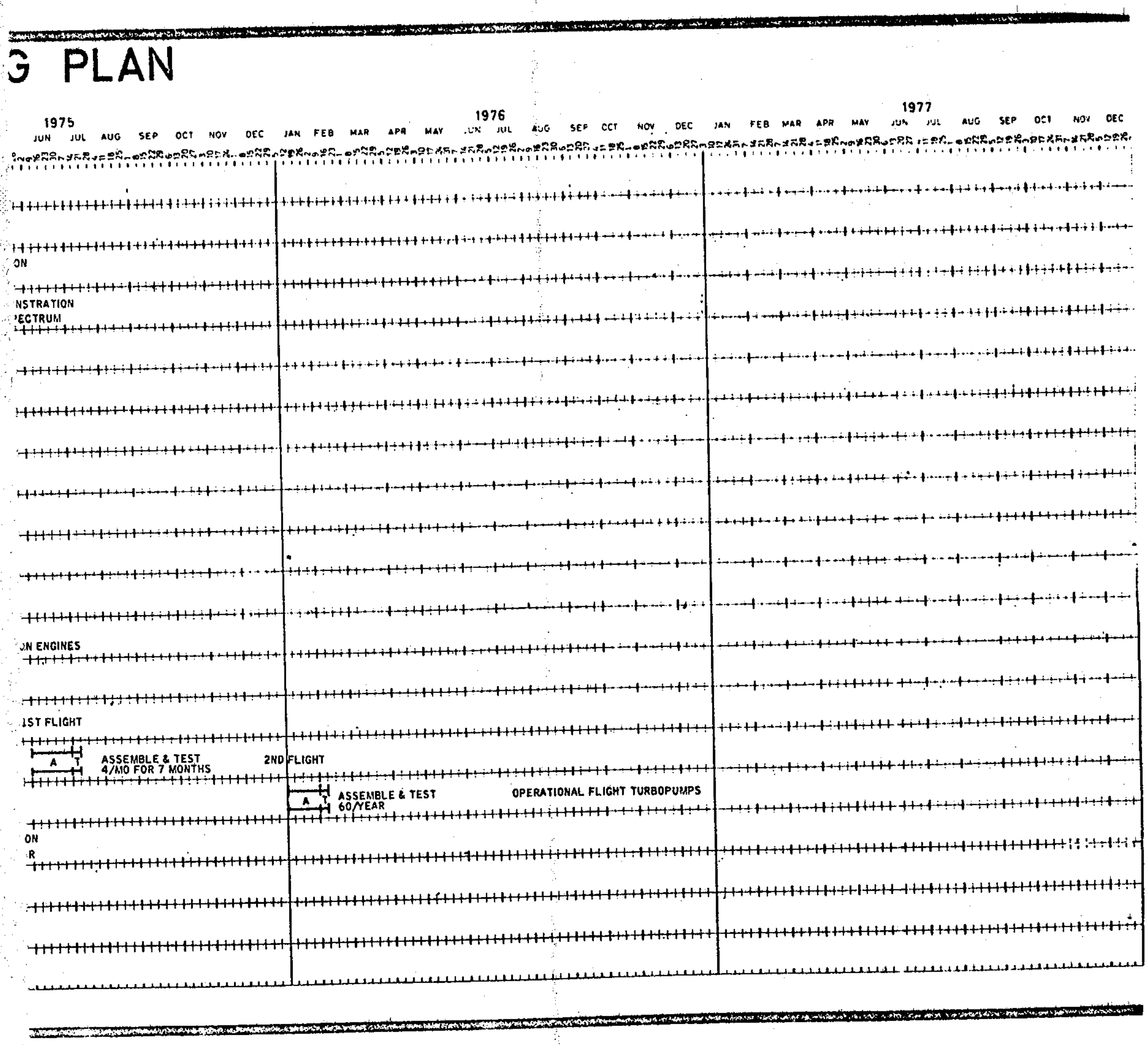


Figure 4. - Current Operating Plan, Full Series Approach (Sheet 2 of 2)

Subcategory 1: Recognized existing technology design limits are established for pumps, seals, turbines, bearings, and structural materials.

Subcategory 2: Parametric analysis of individual subcomponent characteristics is made based upon the design limits established.

Subcategory 3: Design point is selected based upon a combination of the parametric analysis and the cost-contributing operations. This gives specifications for turbopump, engine, and vehicle performance levels and tolerances.

Subcategory 4: Conceptual and final design layouts along with supporting stress and performance calculations.

Subcategory 5: Detailed drafting (turbopump).

Subcategory 6: Subcomponent test article design and turbopump development fabrication release.

Although the above subcategories in themselves are similar to those of the "standard" design phase, they are accomplished sequentially and to a different degree of completion.

In practice, it is found that the establishment of the design limits sets the "ground rules" for the entire task. Government/Contractor technical specialists review these limits before actual design activity is started. Necessary modifications are made at the outset of the program to preclude the unproductive design activity associated with controversial design limits. Once established, these design limits become the basis for the parametric analysis, which serves to provide parametric limits as well as the rate of change for the various dependent parameters as a function of the variables (i.e., speed and NPSH). Thus, the design point can be selected with a full awareness of the effects that small errors will have in the assumed design limits or the cost-contributing operations. Again, the technical specialists review the parametric trends as well as their effects upon cost and performance before the actual design begins.

Next, conceptual design is initiated and preliminary stress as well as performance characteristics are established. This allows analytical determination of the transient and steady-state operation with the interfacing engine/vehicle components. It also permits confirmation of the selection of the parametrically-defined configuration. Fabrication and assembly costs as well as quality control and maintainability are value engineered. The conceptual design and the preliminary operating characteristics are Government/Contractor reviewed for appropriate modification or

final design approval. Upon approval, the design layout is completed in detail (i.e., fluid passage shapes and coordinates, all tolerances, and specifications for material procurement, processing, quality control, and instrumentation fittings). The final stress and materials engineering is accomplished during this last half of the layout subtask using existing Government or Industry specifications defining material properties. The final layout itself includes all pertinent dimensions, clearances, and tolerances as well as material, key fabrication/inspection processes along with the handling, marking, and shipping specifications. It is sufficiently comprehensive to permit detailed drafting to be accomplished without need of any further engineering activity. This completeness allows an in-depth final design review, which includes the quality control and manufacturing requirements. After the final design is approved, most of the design engineering personnel are reassigned in support of other programs. (In a turbopump design activity for the Titan-MOL, the manloading started at five, rose to 24, and returned to five over a 10-month period.) A minimal cadre of design project personnel accomplishes the manufacturing liaison and defines the testing requirements. These personnel are included in estimates of the cost of design operations.

The detailed drawings are completed and verified against the master layout. None of these drawings is released and no fabrication is initiated until the entire set is completed as an additional means for uncovering errors. Experience to date with the "full series" approach shows a 40% reduction in drafting time over the previously-used "standard" system. Also, the number of combined engineering-drafting errors subsequently discovered during manufacturing has been significantly reduced (approximately 1 error per 10 drawings). Further, there is a considerable reduction in release time because all of the detailed design material is available before this effort starts which permits maximum utilization of drafting personnel without regard for the availability of engineering guidance. In addition, the master layout has already been appropriately certified (i.e., manufacturing, stress, quality control, and design); therefore, individual detailed drawing certifications can await the drawing release. Recently, the "full series" approach was utilized in the "Full-Flow Inducer" effort (Contract NAS 3-7977) to produce some 60 drawings defining all of a two-speed inducer system components. These drawings were completed and released within three weeks.

As can be seen on Figures No. 3 and No. 4, the only schedule changes attributable to the "full series" approach occur in the development phase operations and result in an apparent delay of the turbopump qualification program of approximately three to six months. The design costs shown on Tables III and IV and Figures No. 5 and No. 6 reveal that the "full series" approach offers a potential design cost saving of 8.7% or 340,000 for the reference program design phase costs. These savings are probably conservative for an actual program because of the greatly reduced likelihood of committing design errors, especially in the detail drafting operations.

TABLE III. - DESIGN PHASE, DESIGN AND DEVELOPMENT ENGINEERING STANDARD PROGRAM MANPOWER SUMMARY

DISCIPLINE/ACTIVITY	MANPOWER PROGRAM QUARTER																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
STANDARD PROGRAM																					
Pump Hydraulics	4	6	8	16	16	8	4	2	2	0	2	1	1	1	1	1	1	0	0	0	
Turbine Aerodynamics	4	6	8	16	16	8	4	2	2	0	2	1	1	1	1	1	1	0	0	0	
Concept Layout	2	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Thermal Analysis	2	3	4	6	6	6	3	2	2	2	1	1	1	0	0	1	1	0	0	0	
Critical Speed Analysis	1	1	1	1	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	
Structural Analysis	2	5	6	8	10	10	8	4	2	2	2	2	2	1	1	1	2	0	0	0	
Turbopump Layout & Mech Design	0	0	2	4	6	6	6	0	2	0	1	1	0	0	0	0	0	0	0	0	
Fabrication Drawings	0	0	0	4	6	12	12	0	0	2	1	1	0	1	0	0	0	0	0	0	
Tester Design	0	0	0	0	2	7	3	1	0	0	0	0	0	1	0	0	0	0	0	0	
Fabrication Liaison	0	0	0	0	2	3	4	6	6	6	8	6	6	6	4	4	3	2	2	0	
Test Planning & Liaison	0	0	0	0	3	3	4	4	4	5	8	10	10	14	14	9	7	2	2	0	
TOTAL	15	25	32	55	62	64	48	21	20	17	25	24	24	25	21	17	15	4	4	0	

TABLE IV. - DESIGN PHASE, DESIGN AND DEVELOPMENT ENGINEERING FULL SERIES PROGRAM MANPOWER SUMMARY

DISCIPLINE/ACTIVITY	MANPOWER PROGRAM QUARTER																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
<u>FULL SERIES PROGRAM</u>																					
Pump Hydraulics	4	6	10	16	16	4	2	0	0	0	0	2	1	1	1	1	1	1	0	0	0
Turbine Aerodynamics	4	6	10	16	16	4	2	0	0	0	0	2	1	1	1	1	1	1	0	0	0
Concept Layout	2	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thermal Analysis	2	3	5	6	6	2	0	2	2	0	1	1	1	0	0	0	1	1	0	0	0
Critical Speed Analysis	1	1	1	2	2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Structural Analysis	2	5	8	10	10	4	2	4	2	1	1	2	2	1	1	1	1	1	0	0	0
Turbopump Layout & Mech Design	0	0	6	8	14	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fabrication Drawings	0	0	0	0	0	10	10	2	1	2	0	0	0	0	0	1	0	0	0	0	0
Tester Design	0	0	0	0	0	0	3	8	2	0	0	0	0	0	0	1	0	0	0	0	0
Fabrication Liaison	0	0	0	0	0	0	2	6	6	6	8	6	6	6	4	4	3	2	2	2	0
Test Planning & Liaison	0	0	0	0	0	0	0	2	4	5	10	14	14	10	12	11	9	4	2	2	0
<u>TOTAL</u>	15	25	43	58	64	26	23	24	17	14	18	27	26	20	19	20	16	10	4	4	0

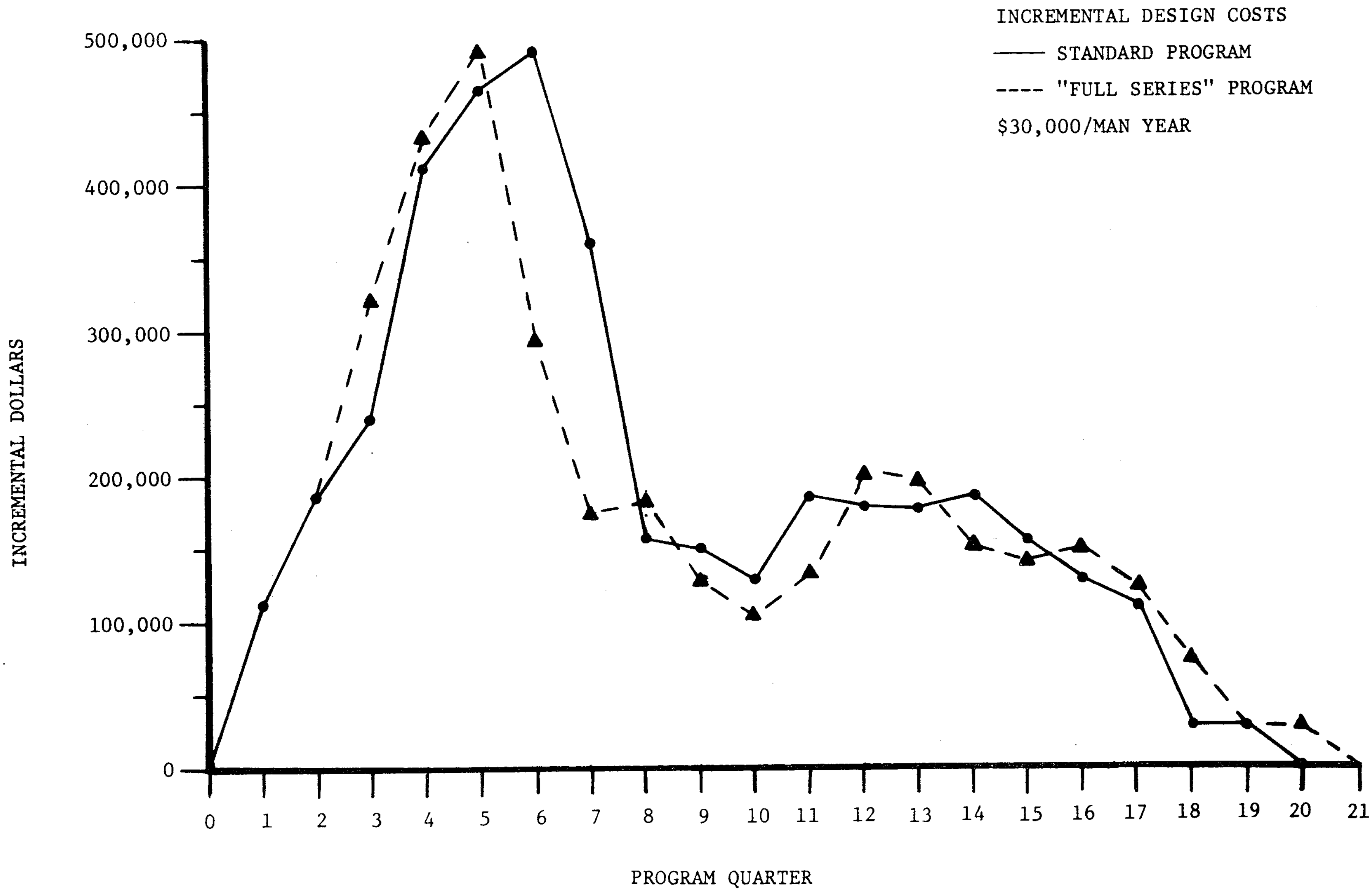


Figure 5. - Incremental Design Costs

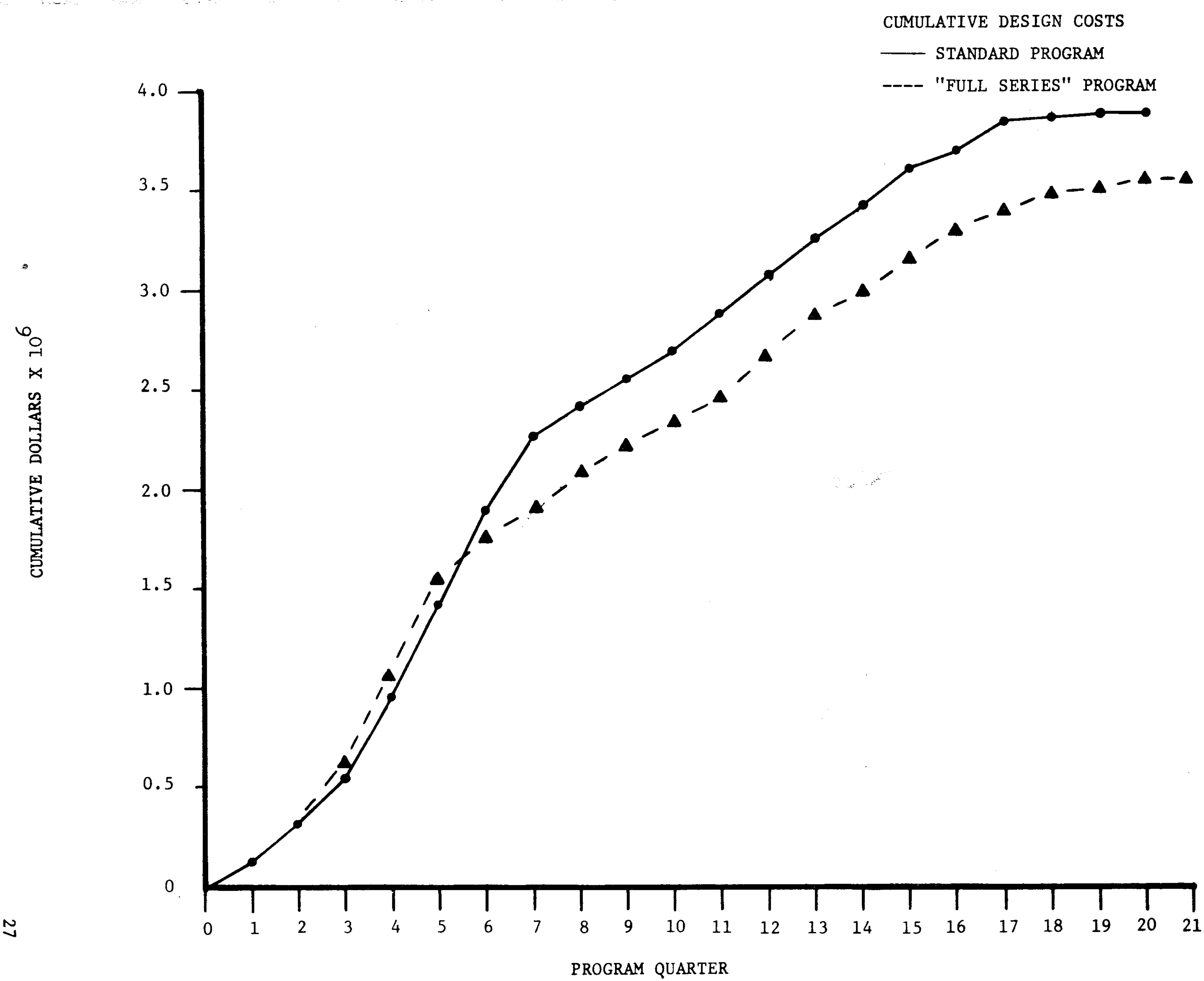


Figure 6. - Cumulative Design Costs

(b) Development Phase Fabrication Operations

Development fabrication operations costs are strongly dependent upon design requirements at the part or subcomponent level. The methodology followed in generating the data used in relating the costs to the requirements was as follows.

The conceptual sketches (Figures No. 1 and No. 2), similar sketches (Figures No. 1 through 10) prepared for higher and lower NPSH requirements, the base case and alternative part level mechanical requirements listing (Appendix C), and actual part fabrication drawings of representative components selected from the Titan, NERVA, and M-1 programs were furnished to several typical aerospace and commercial subcomponent fabricators, including Aerojet-General's own shops. Cost estimates and manufacturing plans were requested at the cost-contributing operation level (see Section III,A,1) for virtually all turbopump subcomponents. All costs wer- requested in terms of both manhours and dollars for production quantities of one (pilot model), 10 (typical R&D order), 40 (initial production quantity), and more than 40 (production runs).

While the response to the requests for cost information was generally quite good, there were several notable exceptions. All of the commercial pump manufactures contacted declined to quote anything other than over-all costs of producing the assembly, implying that their production methods are proprietary information. Also, several vendors declined to quote at any level below that of casting, machining, or welding. The extensiviness of detail in the estimates received precludes their reproduction in this report. However, three sample estimates are included as Appendices E, F, and G. These sample estimates are for the base case fuel turbopump subcomponents as received from two typical aerospace vendors and one commercial job shop. These same data for the base case fuel turbopump reduced composite form with appropriate support and overhead charges applied are presented as Appendix H. Similar data for the base case oxidizer turbopump is included as Appendix I.

Although data in the form of Appendices H and I would provide a solid over-all turbopump fabrication base cost for a contractual program, it is too unwieldly for performing a cost optimization because each requirement variation would result in a separate sheet as well as a separate part cost. Accordingly, the data were interpreted and plotted at the manhour and net dollars level for only those operations that were significantly cost-affected by the requirements variations. The strong production quantity price dependency shown in Appendices H and I further reinforced the conclusion discussed in Section III,A,1 that a test-fail-fix design/development philosophy is not practical and data interpretation was generally limited to the higher quantity production lots.

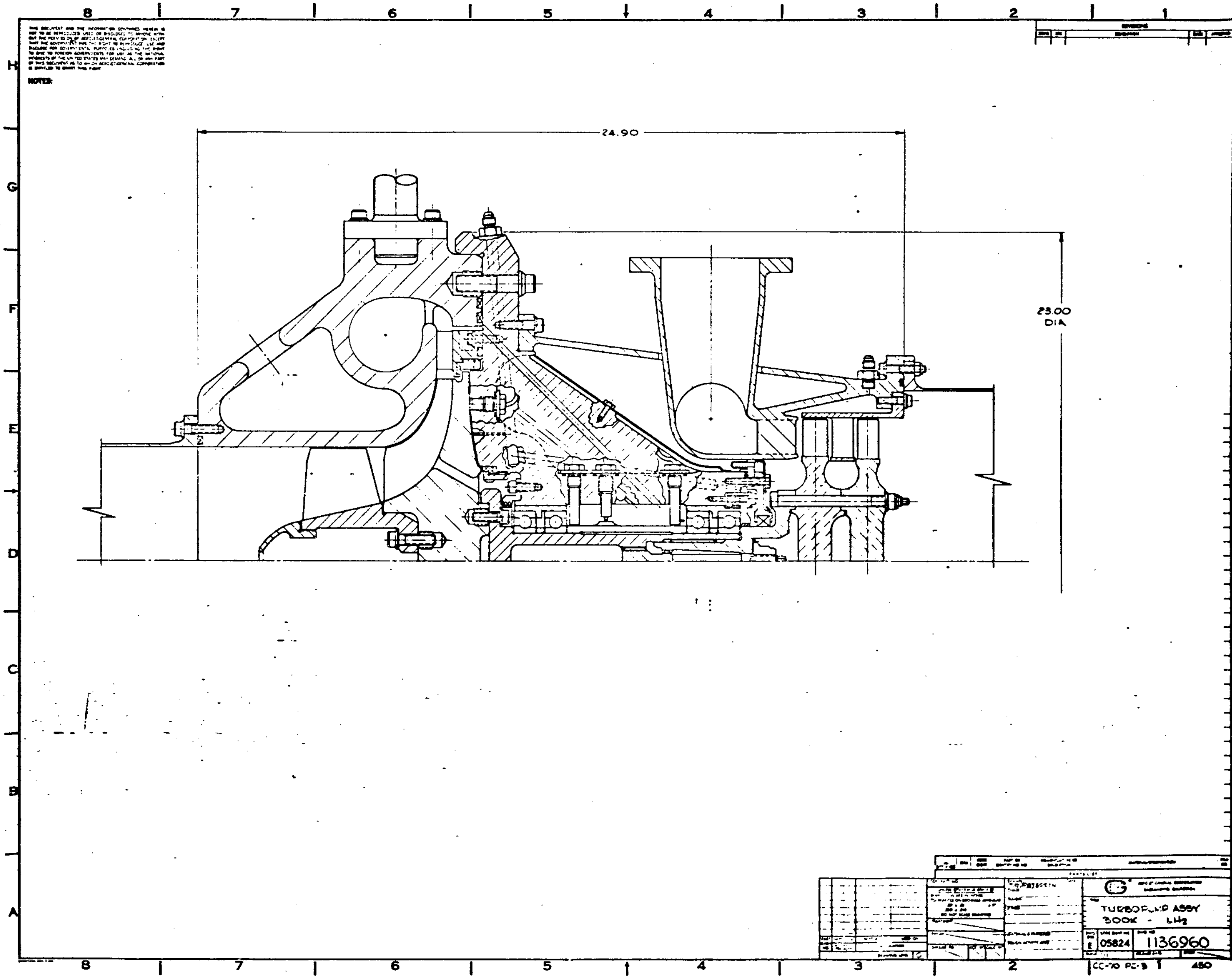


Figure 7. - LH_2 Turbopump Assembly Concept

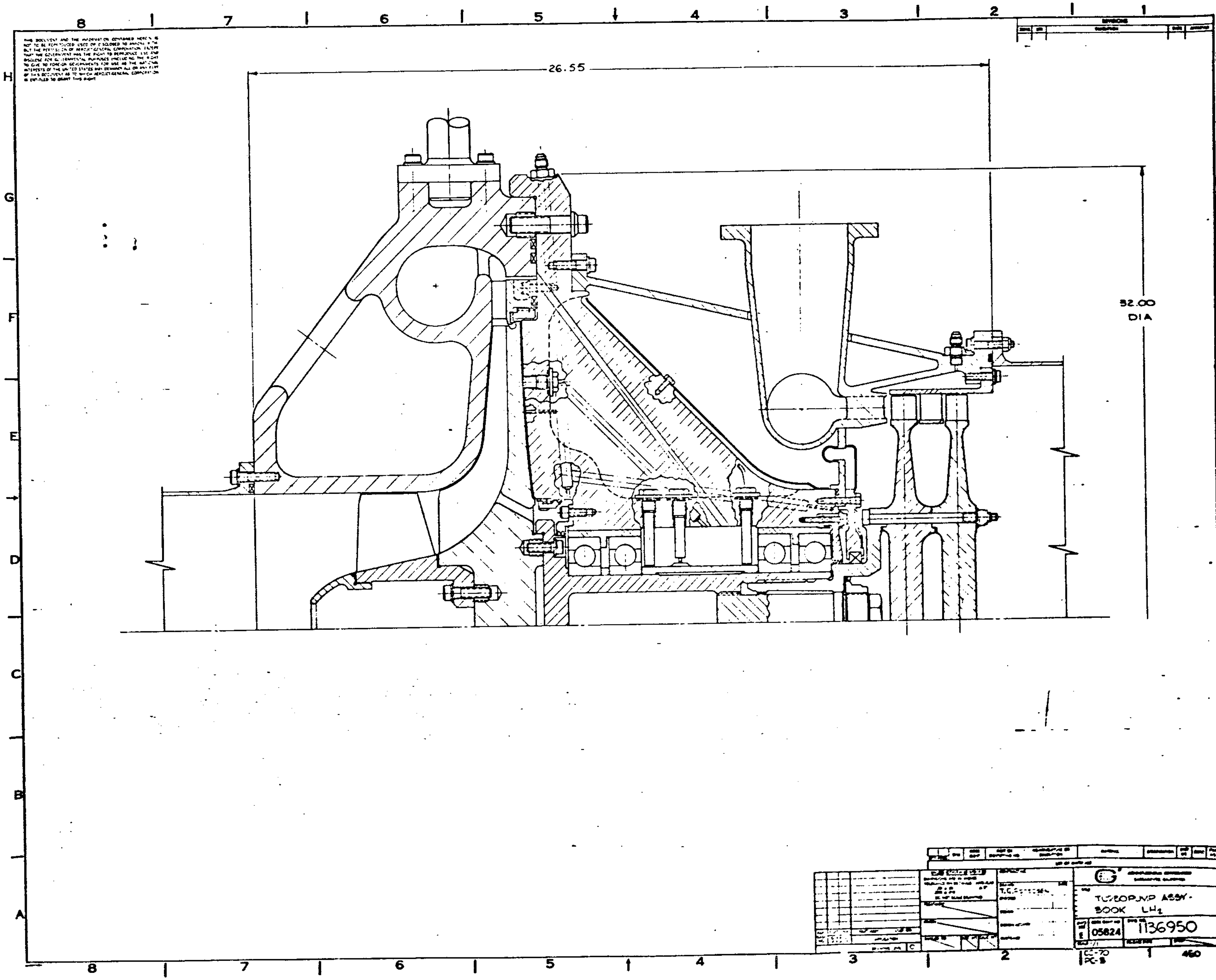


Figure 8. - LH_2 Turbopump Assembly Concept

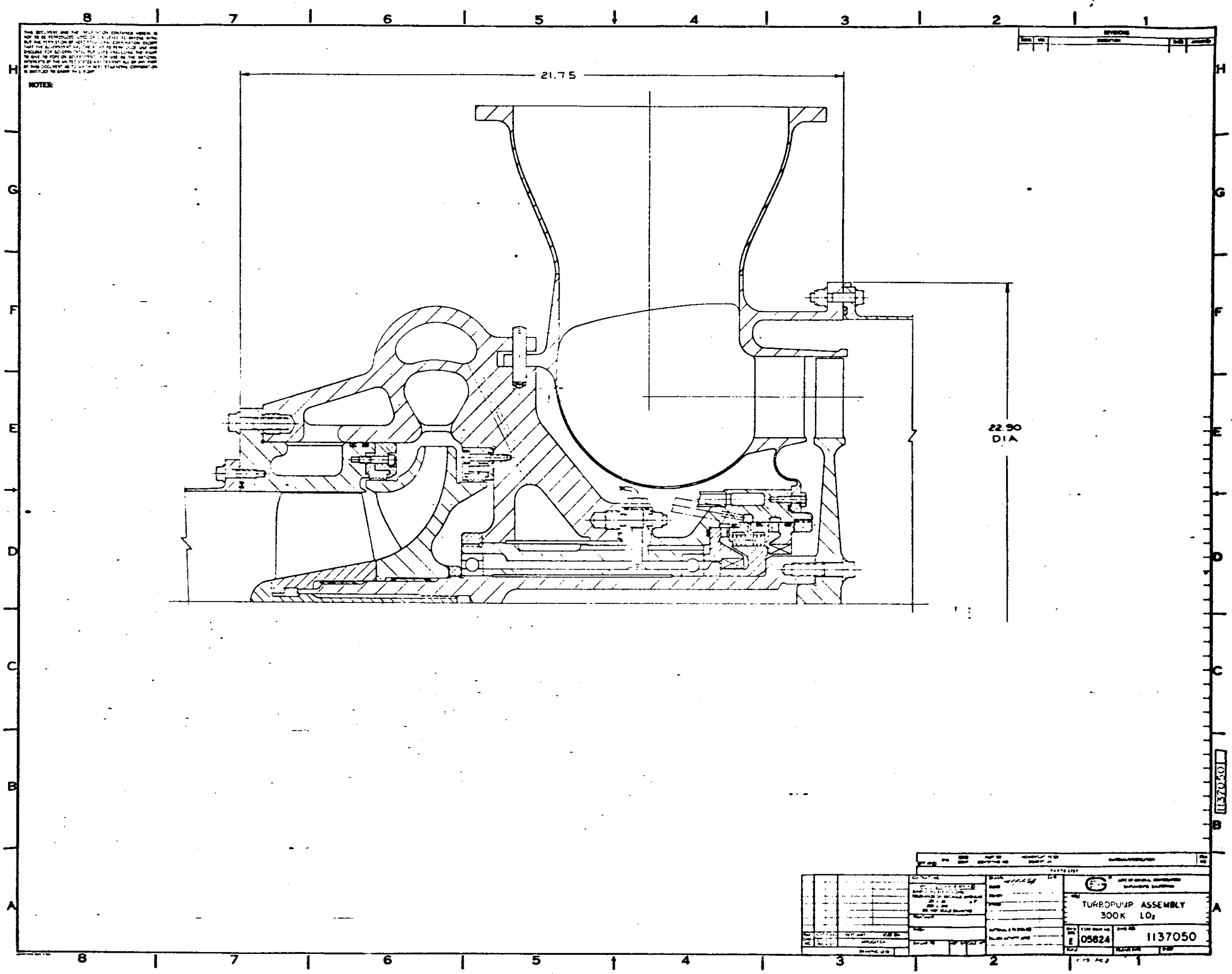


Figure 9. - LOX Turbopump Assembly Concept

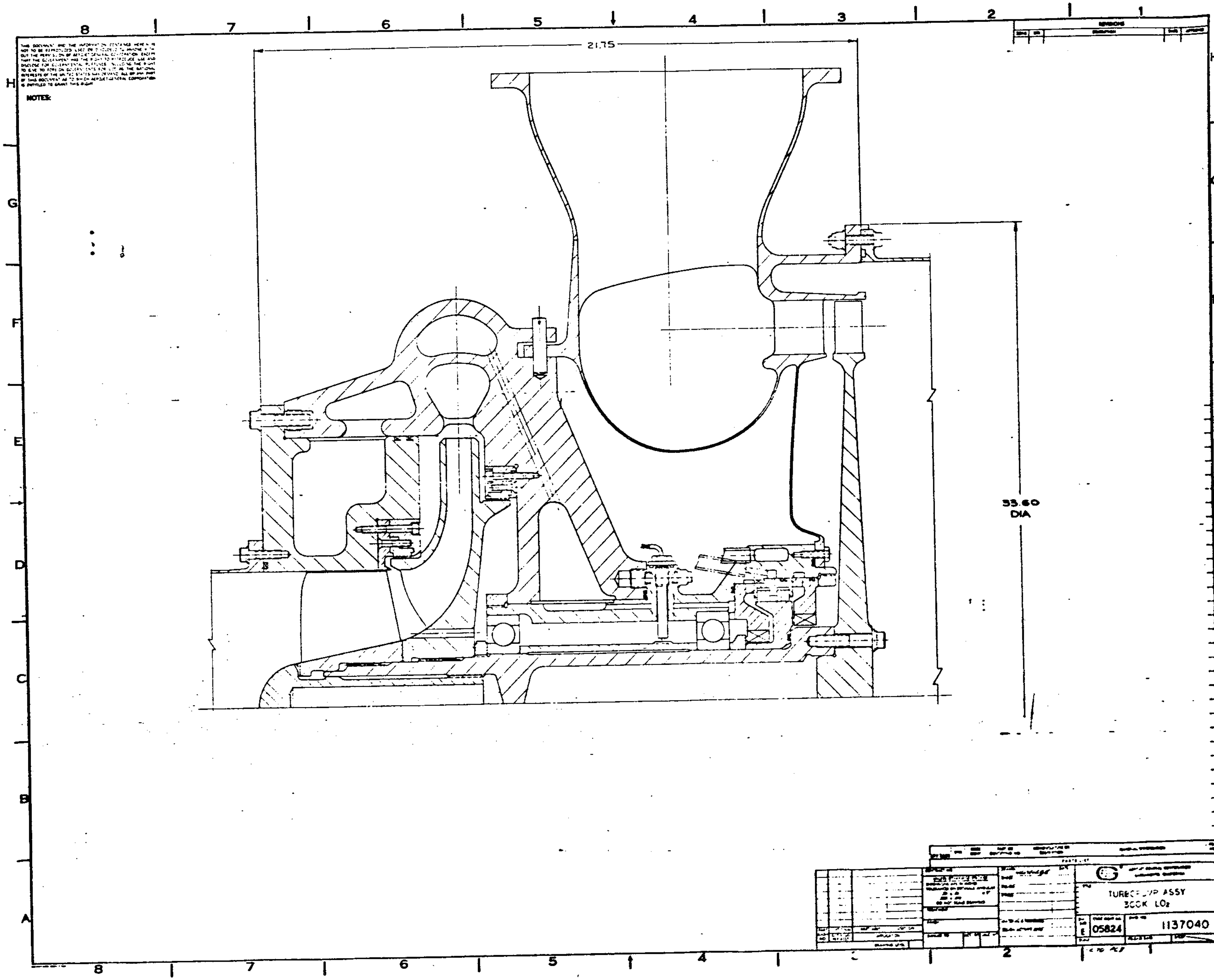


Figure 10. - LOX Turbopump Assembly Concept

A review of the raw (as received) data yielded one overwhelmingly significant fact along with several lesser conclusions. The commercial jobber's prices were significantly lower than the aerospace vendors as expected, but the apparent reason for the price differences was surprising. The hourly dollar rate charged for performing a given operation was for all practical purposes a constant for all vendors contacted, both aerospace and commercial, but the hours estimated to be required to complete an operation varied widely in direct contradiction to the expected result. Extensive discussions with the various estimators provided the following probable reasons for the surprising nature of the results:

- Machinists base hourly pay rates are relatively consistent from shop-to-shop and industry-to-industry.

- The major overhead factor affecting all fabrication specialty shops is the cost of their production machinery. Hence, burdened rates at the various suppliers do not vary significantly.

- The commercial vendors do not fully understand the lost time implications of the quality control requirements usually imposed upon aerospace hardware as evidenced by their price insensitivity to variations in the QC requirements. All aerospace vendors recall similar naivete during their growth period, which results in their listing the quality control requirements as the factor most affecting their higher time estimates.

- The commercial vendors are largely unfamiliar with the difficulties associated with machining the higher strength materials typically used in rocket engine turbopumps. The time estimated by the commercial vendors to complete a given operation is, therefore, significantly in error and they would be unable to produce the components for the prices or on the schedules quoted.

The overwhelming conclusion from the above discussions is that a large body of the data collected during the course of this study is not useful in determining cost optimum requirements. Further, data interpretation was necessarily limited, for the most part, to that obtained from the typical aerospace vendors. Limited use of the commercial vendor data was made where subcomponents could be fabricated from conventional strength materials and quality was easily controlled to the level required by reliability considerations.

As a consequence the requirements versus cost data in the ensuing discussions are almost exclusively derived from estimates supplied by accredited aerospace vendors as well as Aerojet historical records. Significant fabrication operations are discussed and plotted by fuel and oxidizer subcomponent in the same order they are shown in Appendices H and I. Cost versus NPSH/size data are shown for several representative fuel and oxidizer subcomponents. Turbopump unit cost versus NPSH/size data also are included.

1 Fuel Turbopump Item 1 - Fuel Pump Backplate/Bearing Housing

a Casting Tolerance

Figure No. 11 shows the cost effect of casting tolerance. The cost of the parts is almost entirely a function of scrap rate. A typical tolerance of ± 0.030 on flow passage and structural features results in a scrap rate of approximately 12%; split one-third for dimensional defects and two-thirds for casting flaws such as porosity and inclusions. Only the dimensional defect rate is affected by the casting tolerance, with the rate increasing four times at a tolerance of ± 0.020 and decreasing to zero at approximately ± 0.050. It is possible that the scrap rate curve knee could be moved to lower tolerance levels by investment casting but at a sharply increased cost because of the technique development required for such large sized components.

b Surface Finish

Figures No. 12 and No. 13 show the cost effect of surface finish requirements for general machining and hand-finishing operations. The reduction in costs shown would flatten dramatically if extended to higher roughness values. At a roughness of approximately 250, general machining time is dictated by dimensional tolerance and hand-finishing becomes a simple deburring operation to remove sharp edges.

c Critical Dimension Tolerance

Figures No. 14 and No. 15 give the cost effect of critical dimensional tolerances such as the tolerances on pilot diameters, axial stacking planes, and bearing bores. Machining time

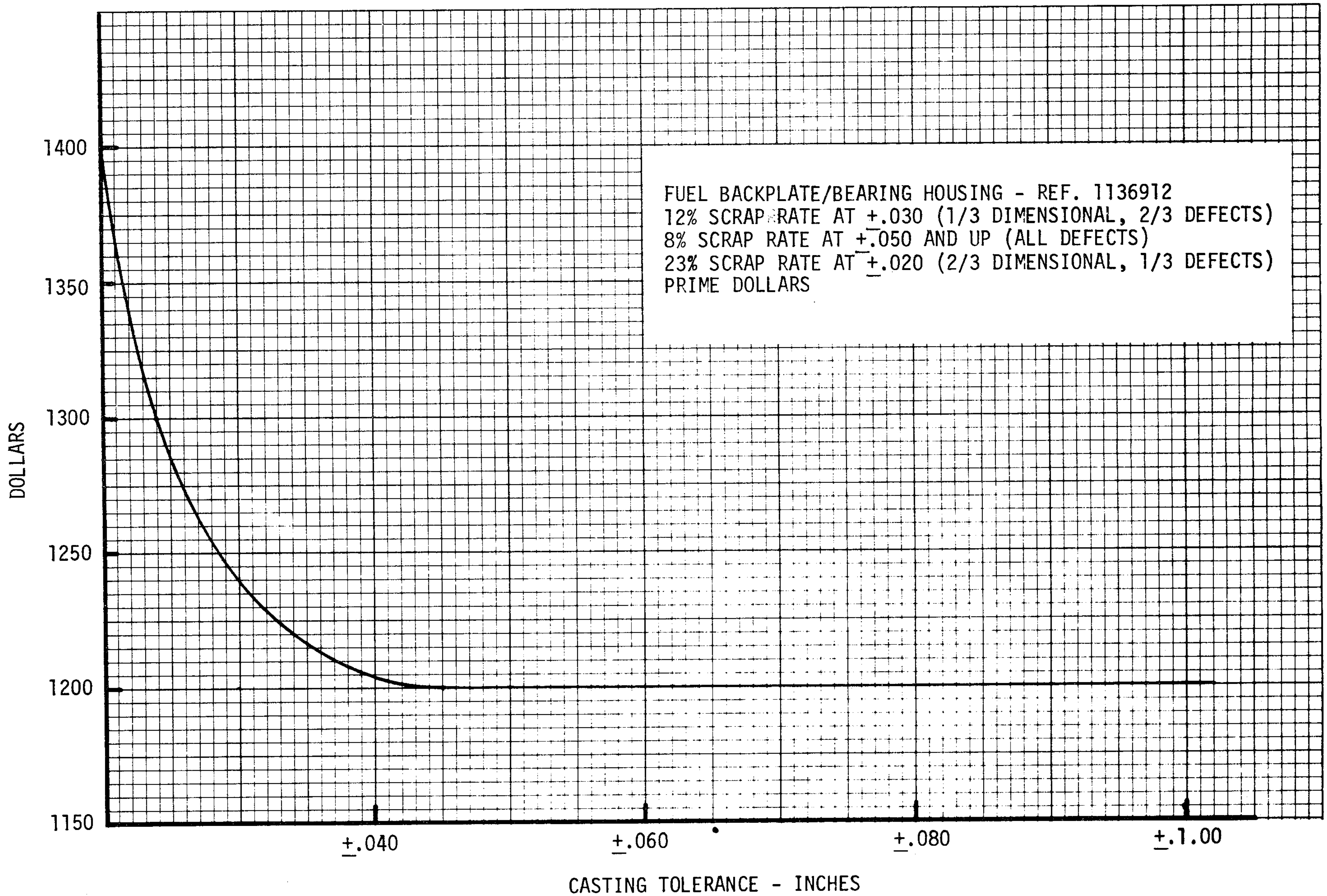


Figure 11. - Cost Effect of Casting Tolerance, Fuel Pump Item 1

F 11, 11

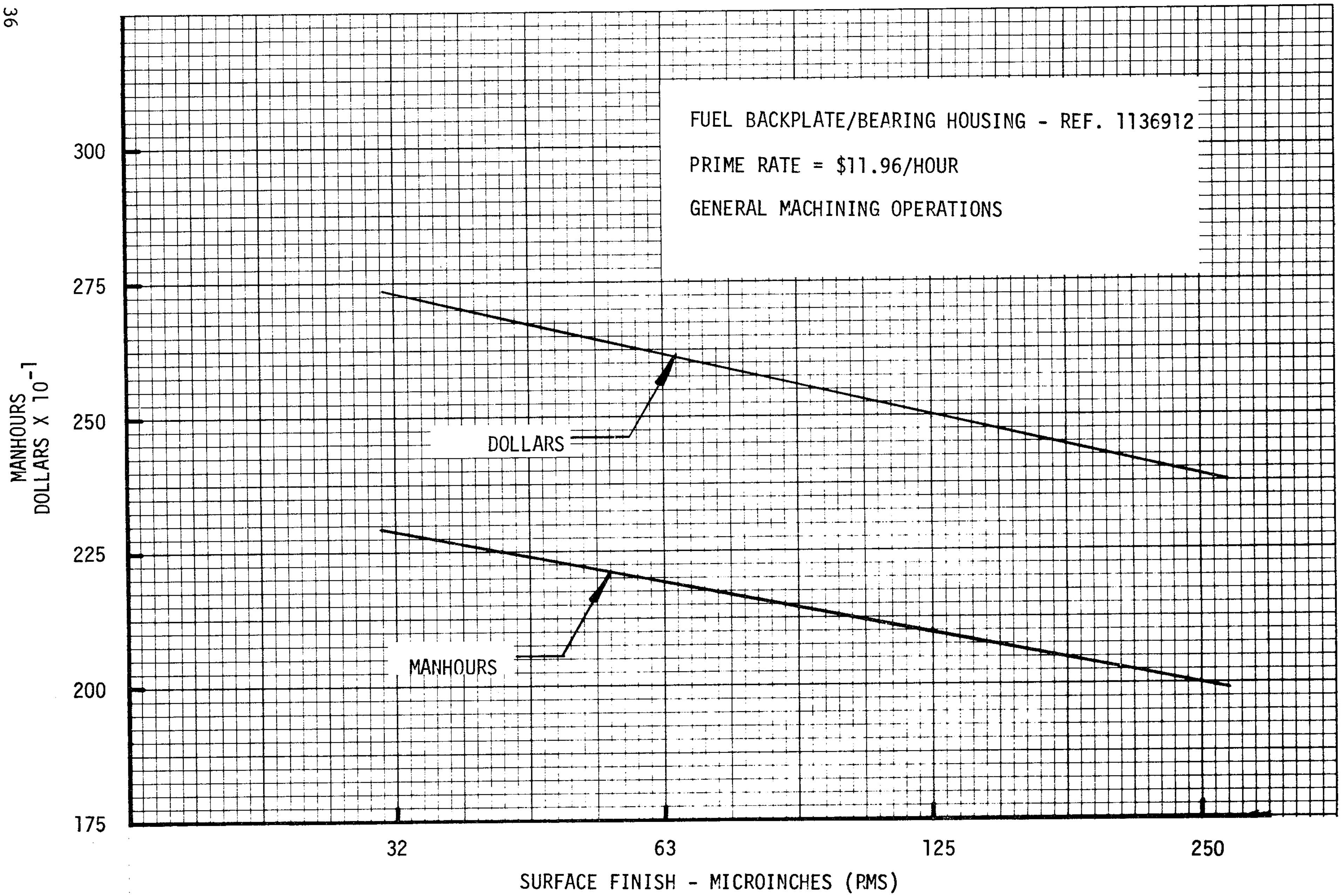


Figure 12. - Cost Effect of Surface Finish (General Machining), Fuel Turbopump Item 1

Fig. 12

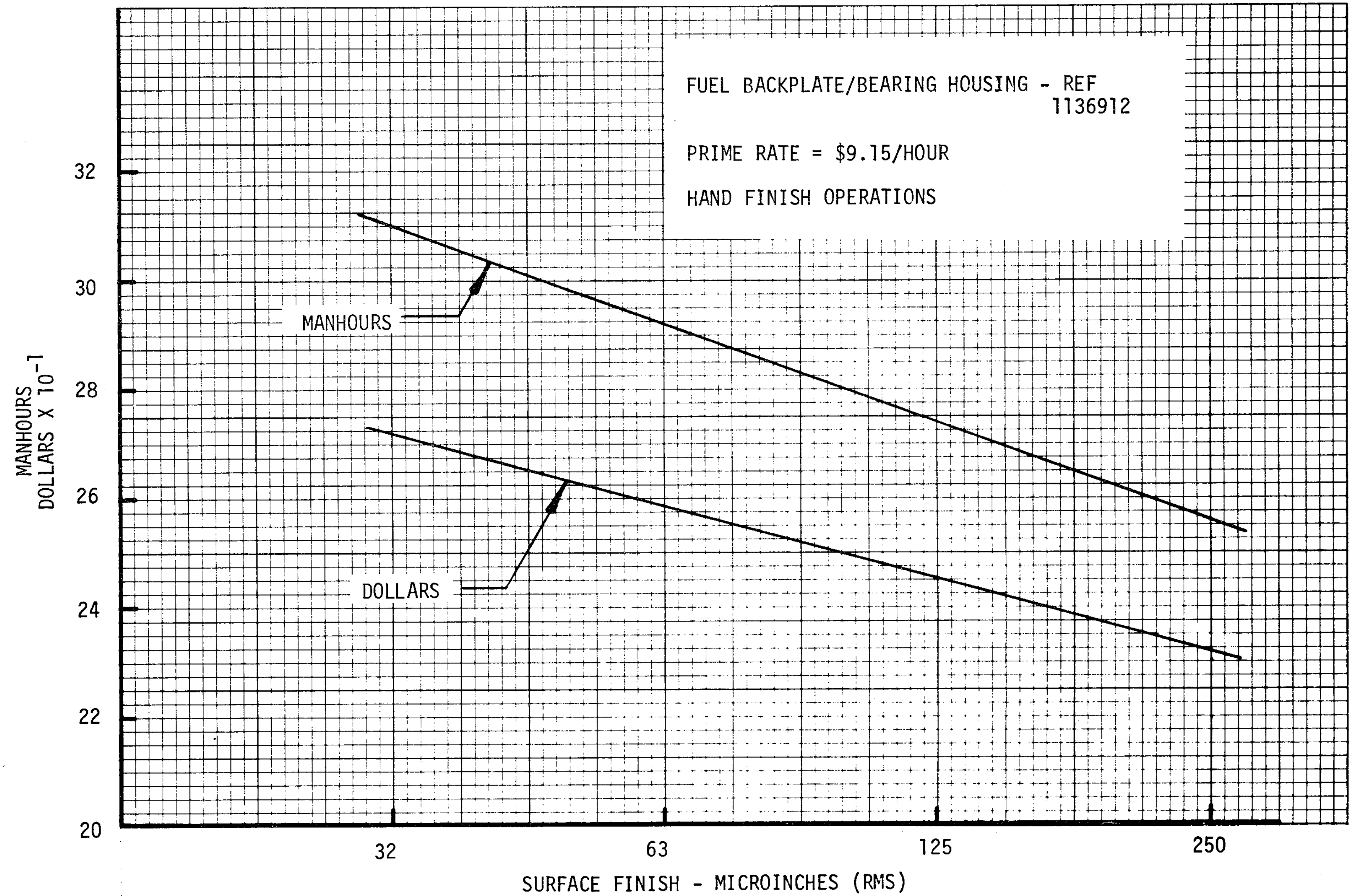


Figure 13. - Cost Effect of Surface Finish (Hand-Finish), Fuel Turbopump Item 1

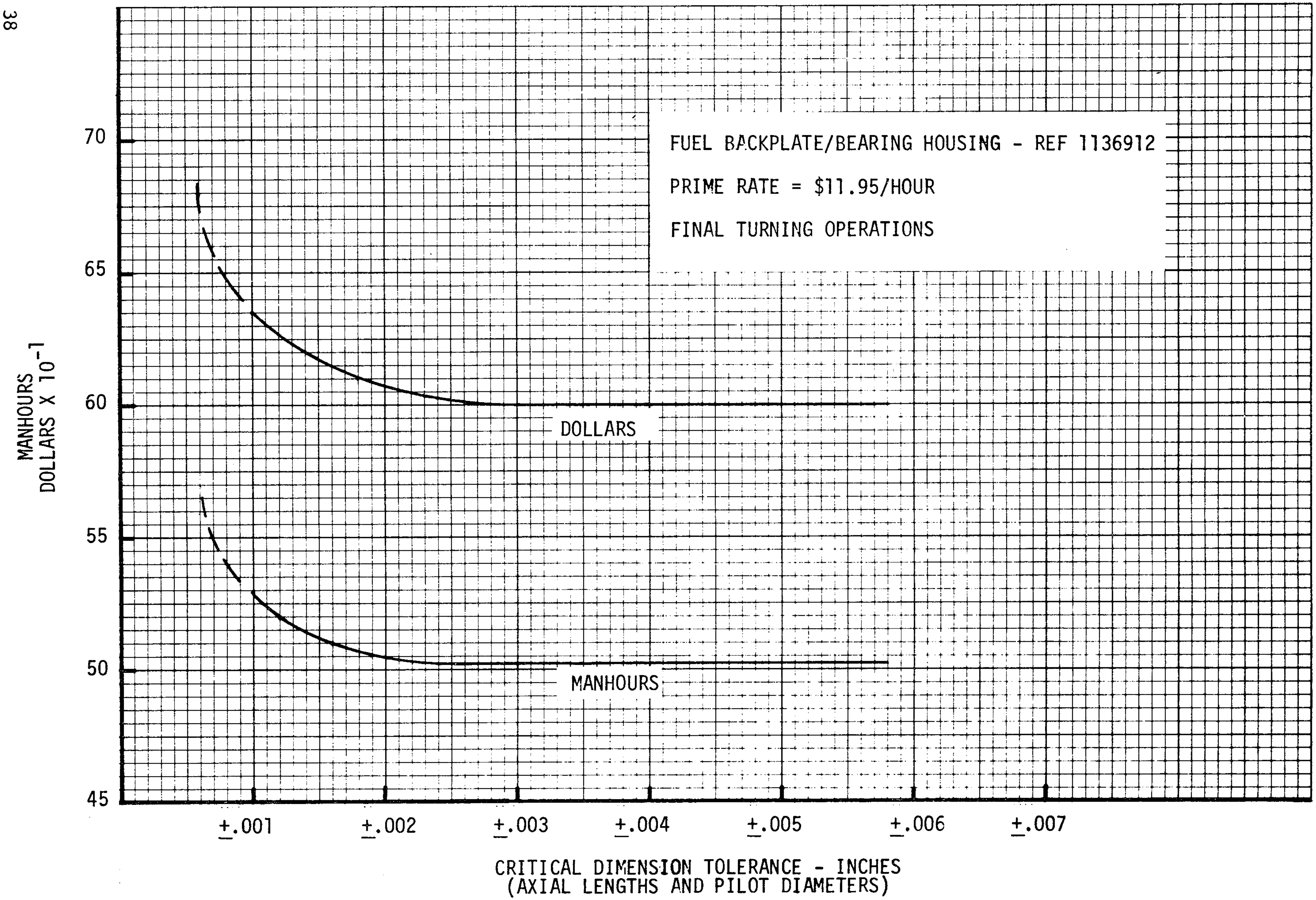


Figure 14. - Cost Effect of Critical Dimension/Tolerance (Final Turning), Fuel Turbopump Item 1

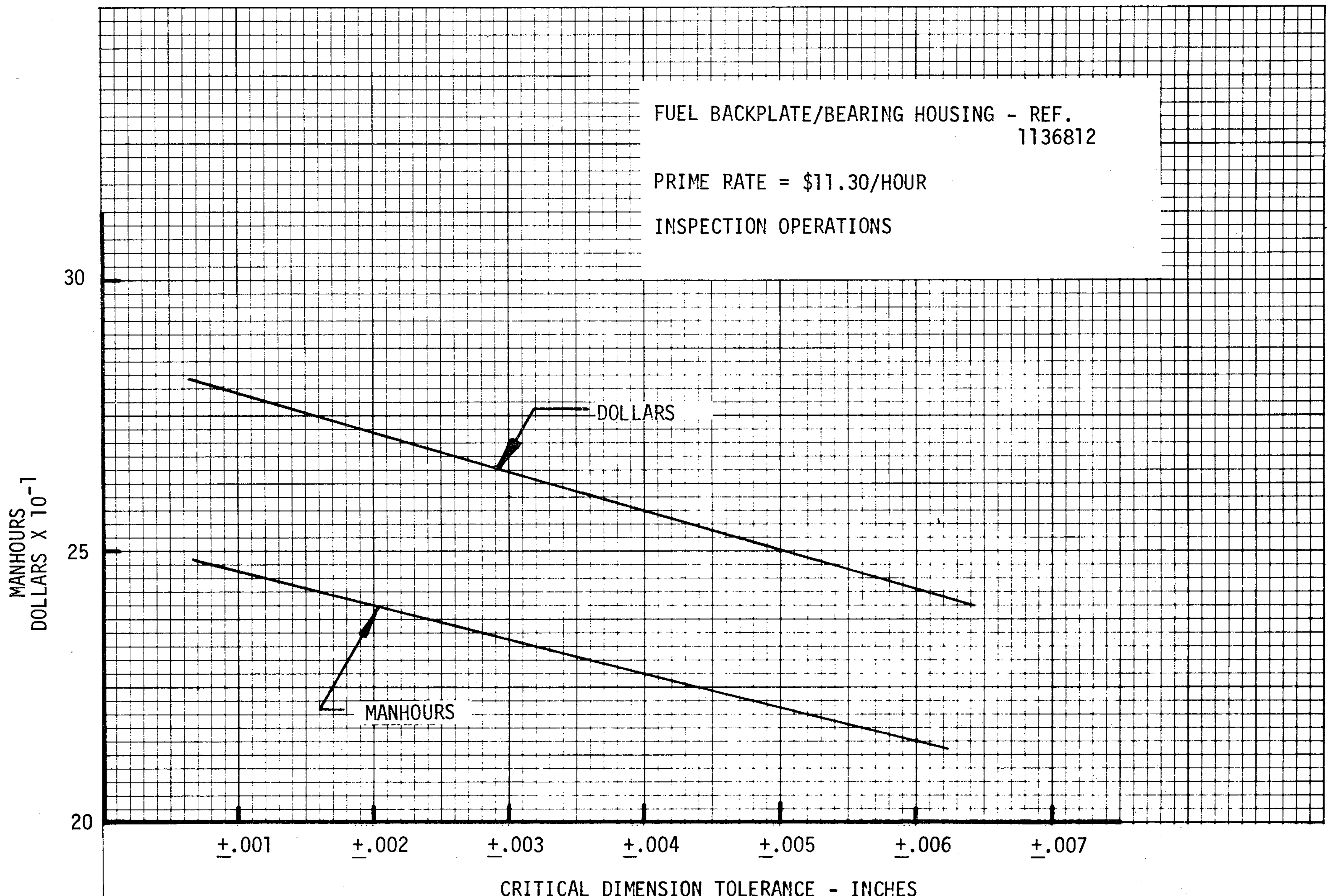


Figure 15. - Cost Effect of Critical Dimension/Tolerance (Final Turning), Fuel Turbopump Item 1

reduces rapidly by approximately 20% from ± 0.0005 to ± 0.003 tolerance but little effect is noted at higher tolerances. Inspection time decreases linearly by 25% over the range from ± 0.0005 to ± 0.010 tolerance but the plots are terminated at approximately ± 0.005 where interference loads in the pilot flanges become excessive.

d Size Effect

Figure No. 16 shows the cost effects of over-all size for the casting and lumped machining operations at the base case tolerances. Combinations at different tolerances can be scaled directly using these data.

2 Fuel Turbopump Items 18 and 19 - Fuel Turbine Rotors, Stages 1 and 2

a General Dimensional Tolerance

The cost effect of general dimensional tolerances (i.e., outside diameter and axial length) is shown on Figure No. 17. The rather small (4% to 5%) cost reduction shown occurs in the range from ± 0.001 to ± 0.003 with no significant improvement from ± 0.003 out to ± 0.005.

b Surface Finish

Figure No. 18 displays a significant (8% to 10%) cost effect of surface finish over the range from 32 microin. to 250 microin. roughness. For the pump backplate/bearing housing, the effect would flatten at approximately 250 microin. when dimensional variations limit machining time. Significant further improvement could be obtained if as-forged or as-forged and sandblasted dimensional variations could be tolerated on the disc surfaces.

c Blade Profile Tolerance

A very strong (20% to 25%) cost effect of rotor blade profile tolerance is shown on Figure No. 19. Primary reasons for the reduction is the reduced cutter replacement/sharpening time and the increased depth of cuts possible at the higher tolerances.

d Size Effect

Cost effects of general size for lumped forging and machining operations at the base case tolerance level are shown on Figure No. 20.

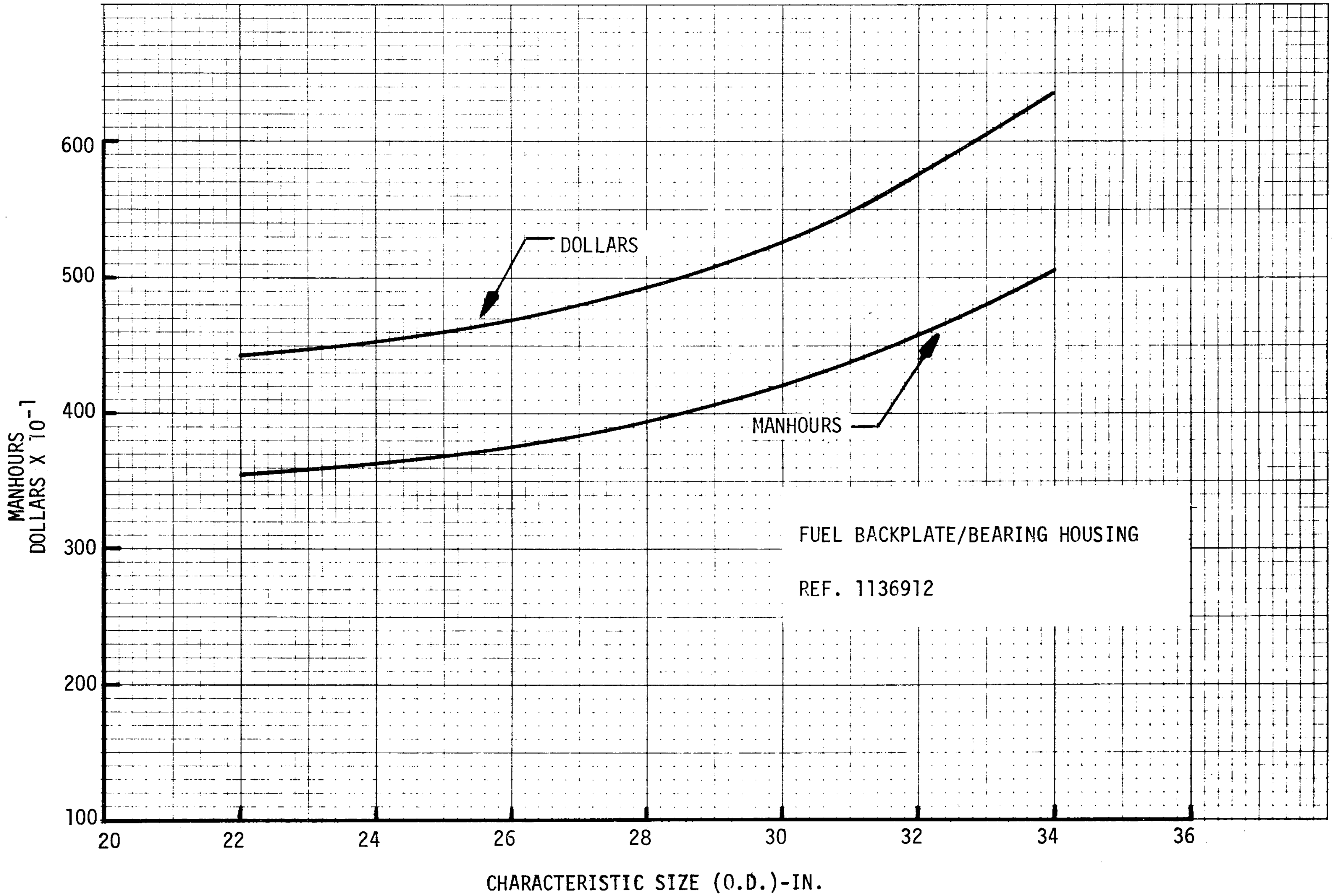


Figure 16. - Cost Effect of Size, Fuel Turbopump Item 1

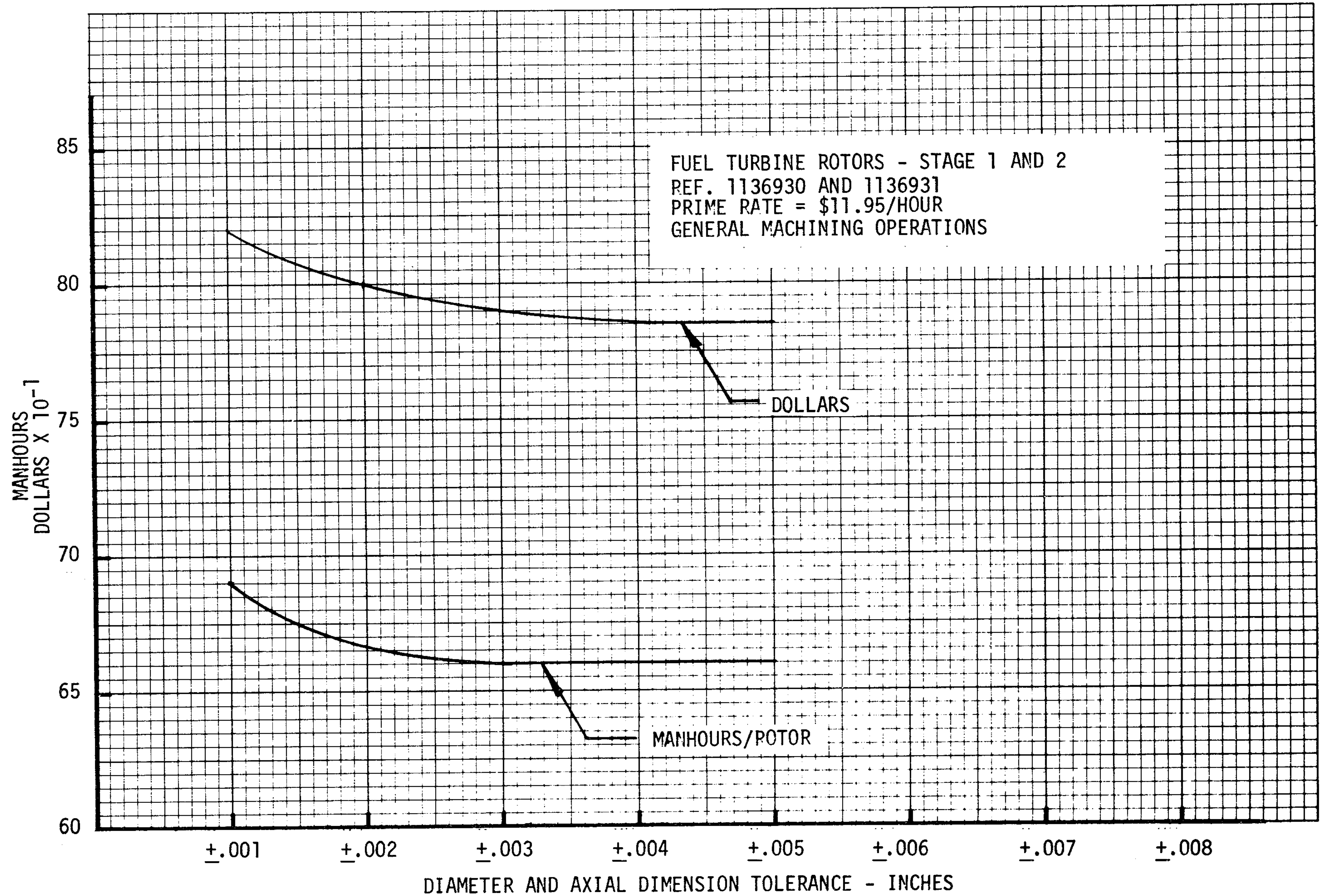


Figure 17. - Cost Effect of General Dimensional Tolerance, Fuel Turbopump Items 18 and 19

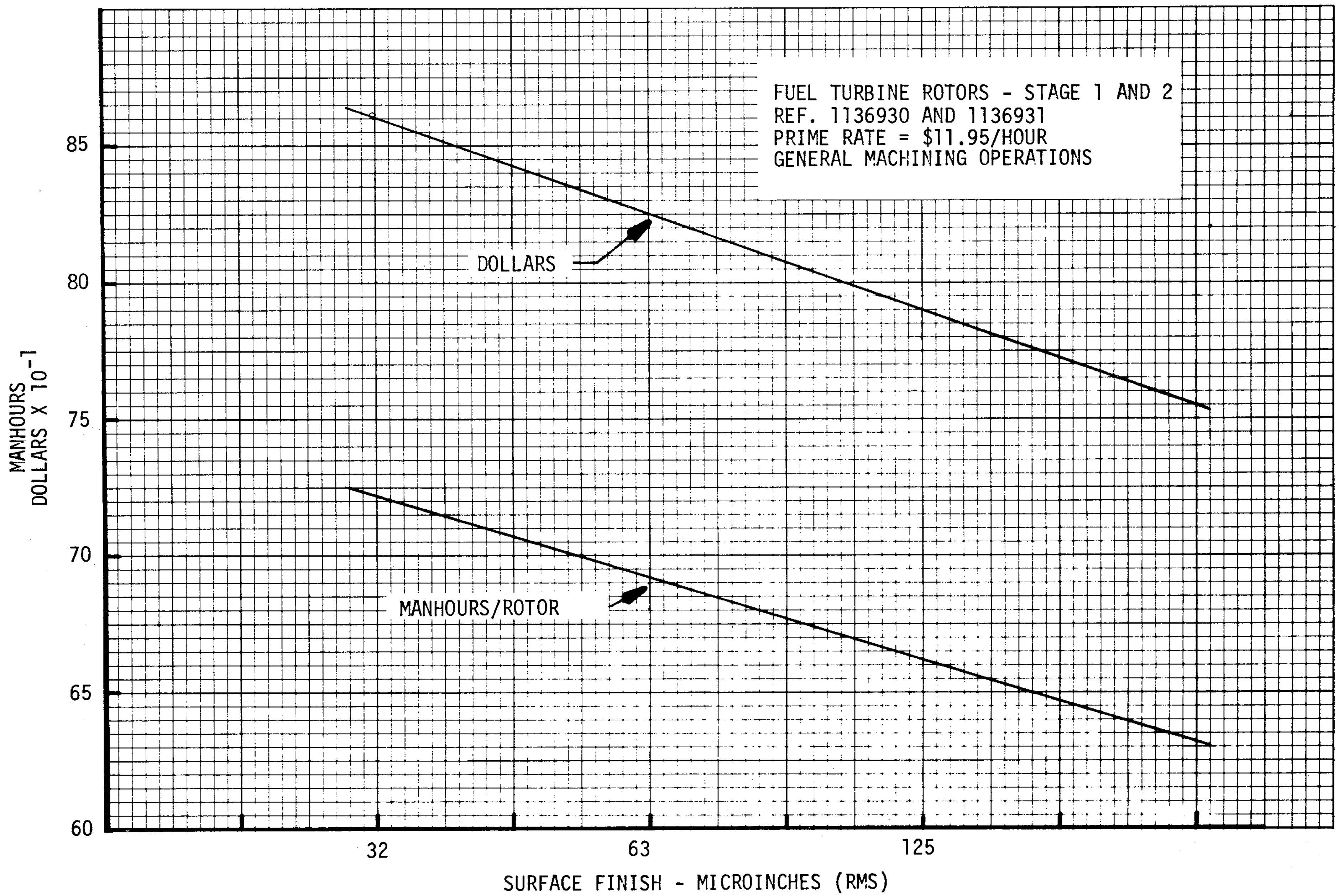


Figure 18. - Cost Effect of Surface Finish, Fuel Turbopump Items 18 and 19

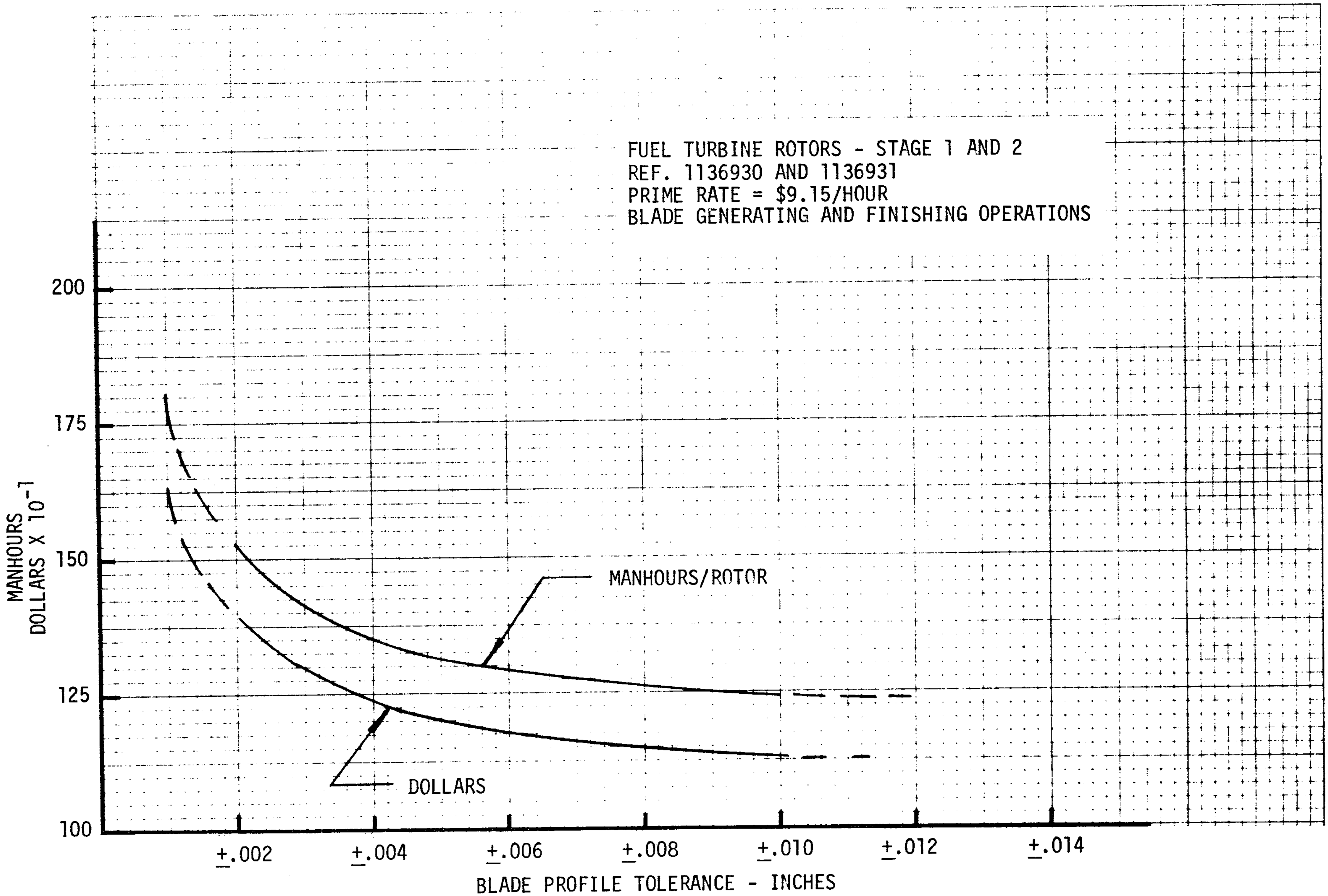


Figure 19. - Cost Effect of Blade Profile Tolerance, Fuel Turbopump Items 18 and 19

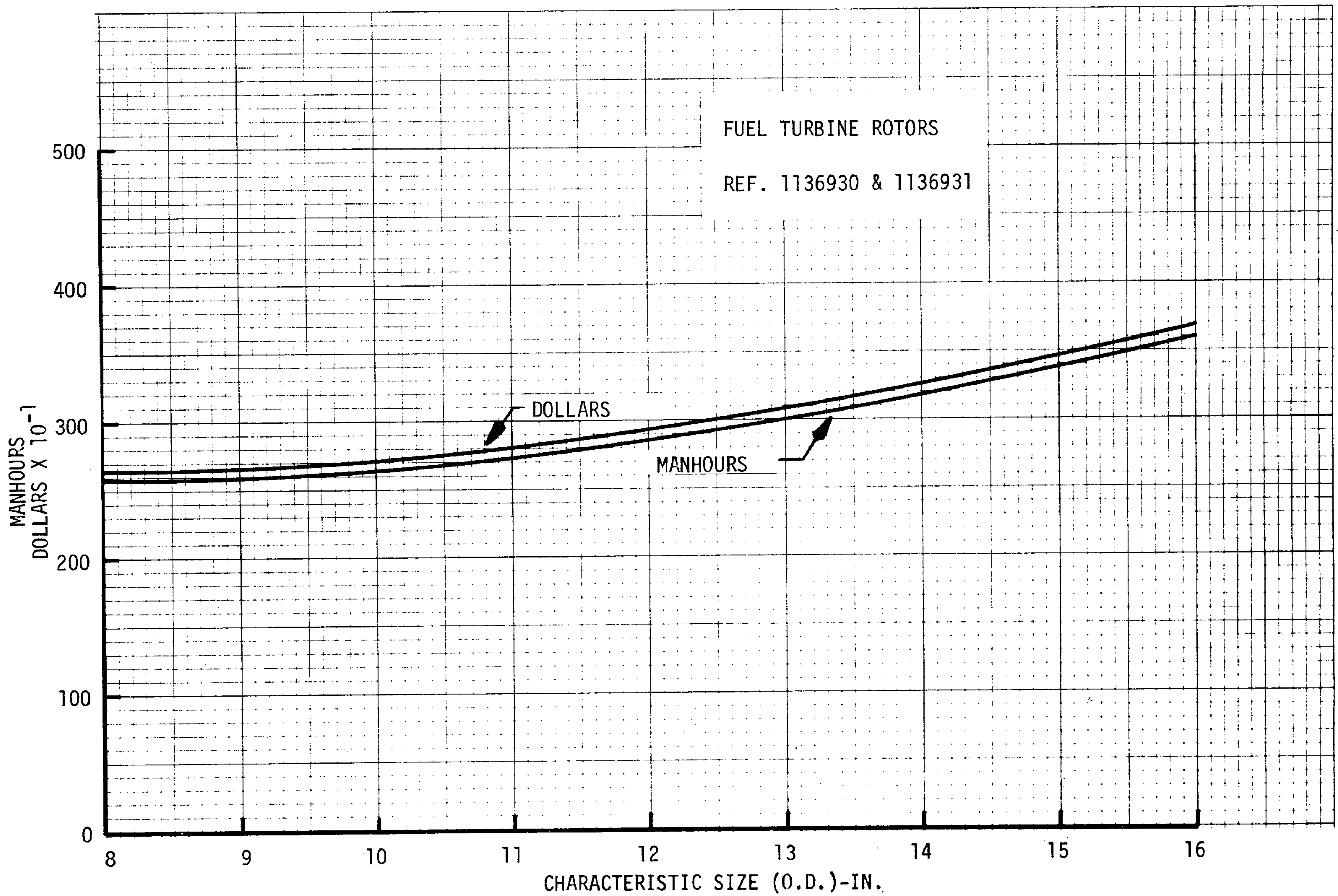


Figure 20. - Cost Effect of Size, Fuel Turbopump Items 18 and 19

3 Fuel Turbopump Item 21 - Fuel Turbine Stator

a Vane Profile Tolerance

Figure No. 21 gives the cost effect of stator vane profile tolerance for vane generating operations. The cost trend line flattens at a tolerance of approximately ±0.005 when surface finish considerations limit the required machining time.

b Surface Finish Vanes

Figure No. 22 shows a significant cost effect of vane surface finish over the 32 microin. to 250 microin. range. Extrapolated reductions in cost below the level shown at 250 microin. where hand finishing costs are eliminated would not be valid. Some additional cost reduction could be obtained at higher roughness values but the rate of improvement is sharply reduced.

c General Surface Finish

Similar reductions in the general machining costs are shown on Figure No. 23. Again, significant further improvement could be obtained if as-forged dimensional variations could be tolerated.

d Size Effect

Figure No. 24 displays the effect of over-all size upon lumped forging and machining operations at the base case tolerances.

4 Fuel Turbopump Item 29 - Fuel Pump Diffuser

a Vane Profile Tolerance

The effect of pump diffuser vane profile tolerance upon vane generating operations costs is shown on Figure No. 25. The upper curves are for a fully-machined version using a typical CRES material. The lower curves represent a combination die cast and machined version using a tens-50 type aluminum alloy. Both sets of curves show significant increases in cost at tolerances tighter than approximately ±0.005. It is significant to note that the die cast model would incur no vane generating costs if tolerances on the order of ±0.010 can be tolerated.

b Surface Finish

Figure No. 26 gives similar hand-finishing cost effects of surface finish for the two diffuser models. The cast

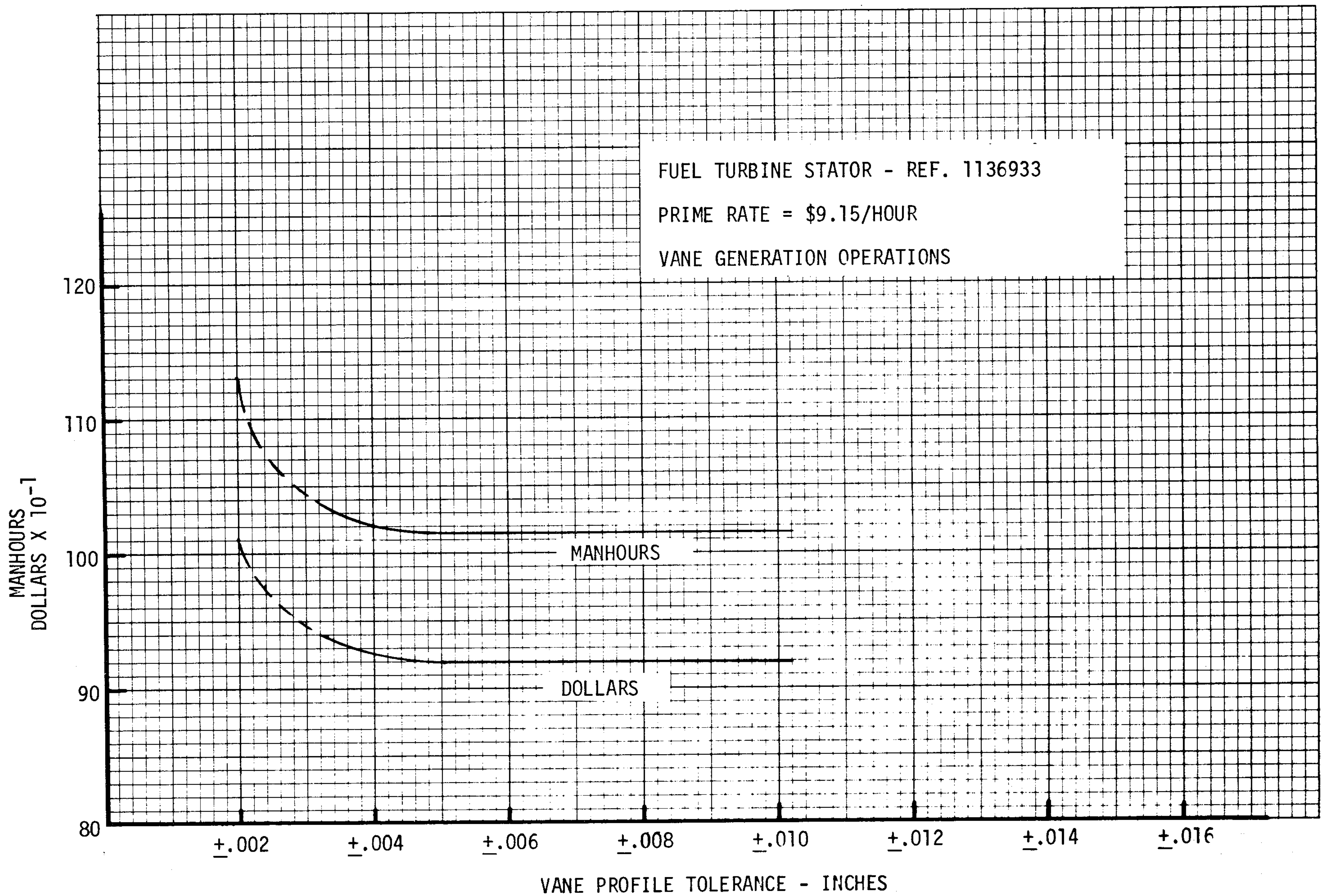


Figure 21. - Cost Effect of Vane Profile Tolerance, Fuel Turbopump Item 21

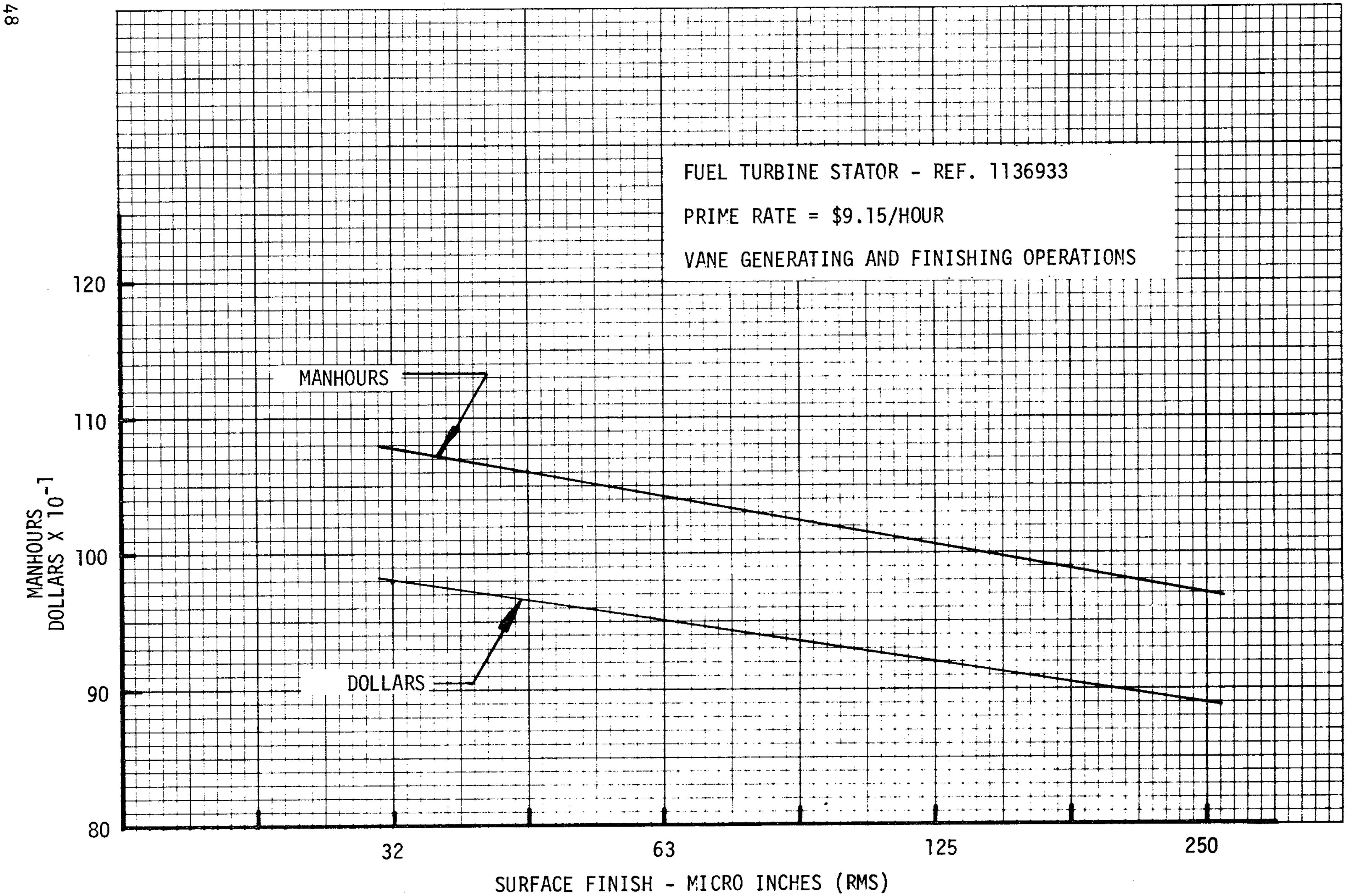


Figure 22. - Cost Effect of Surface Finish (Vanes), Fuel Turbopump Item 21

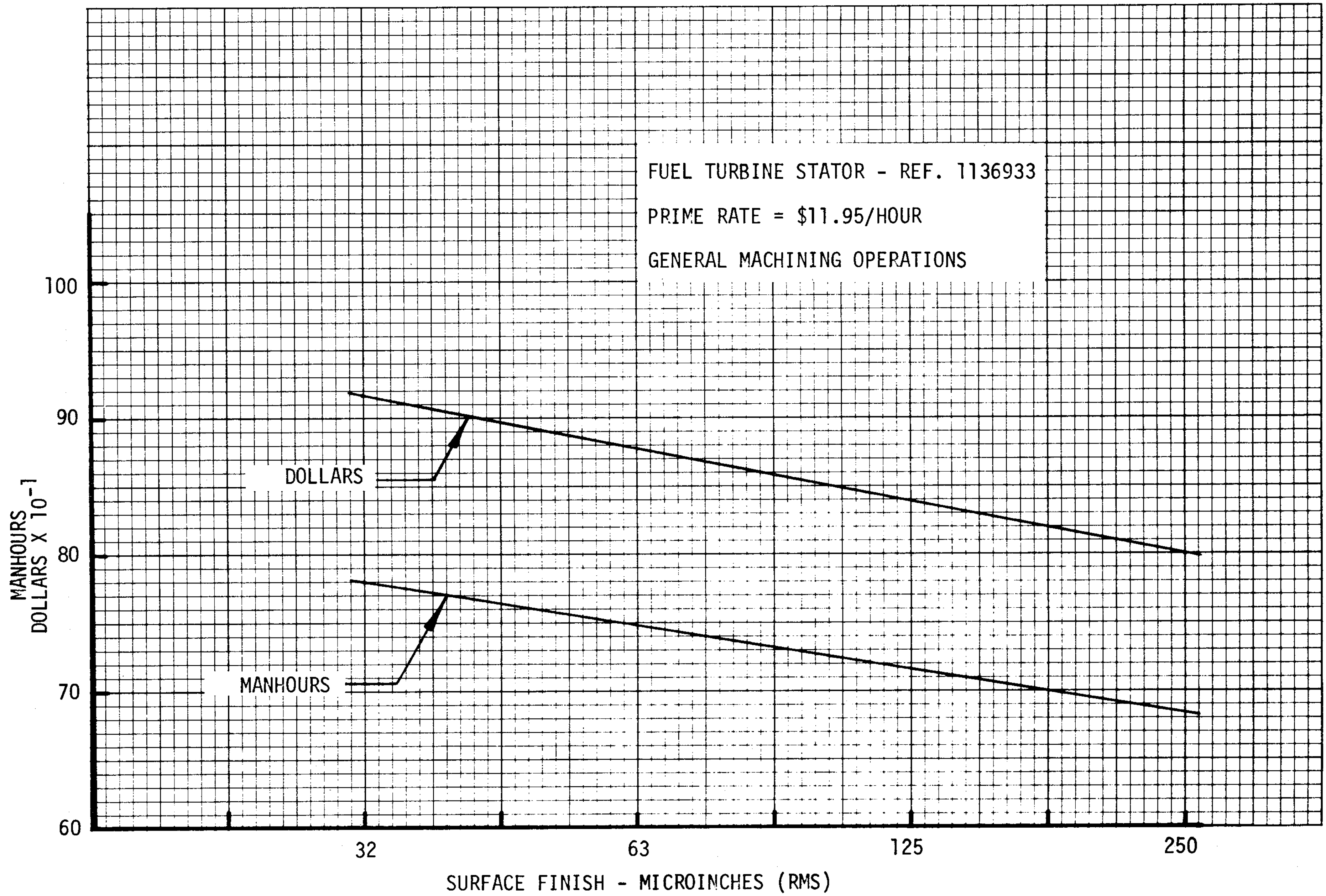


Figure 23. - Cost Effect of Surface Finish, Fuel Turbopump Item 21

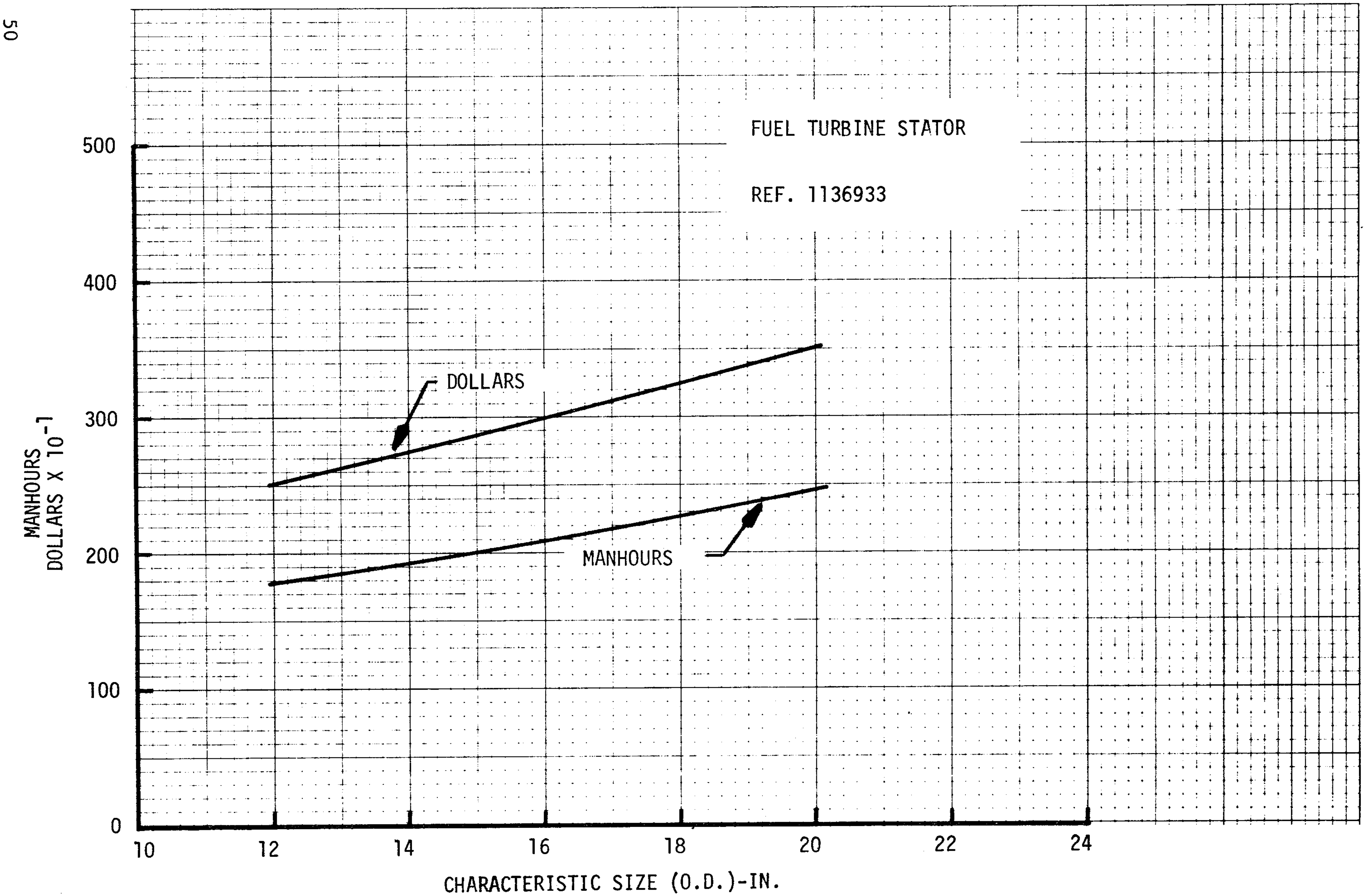


Figure 24. - Cost Effect of Size, Fuel Turbopump Item 21

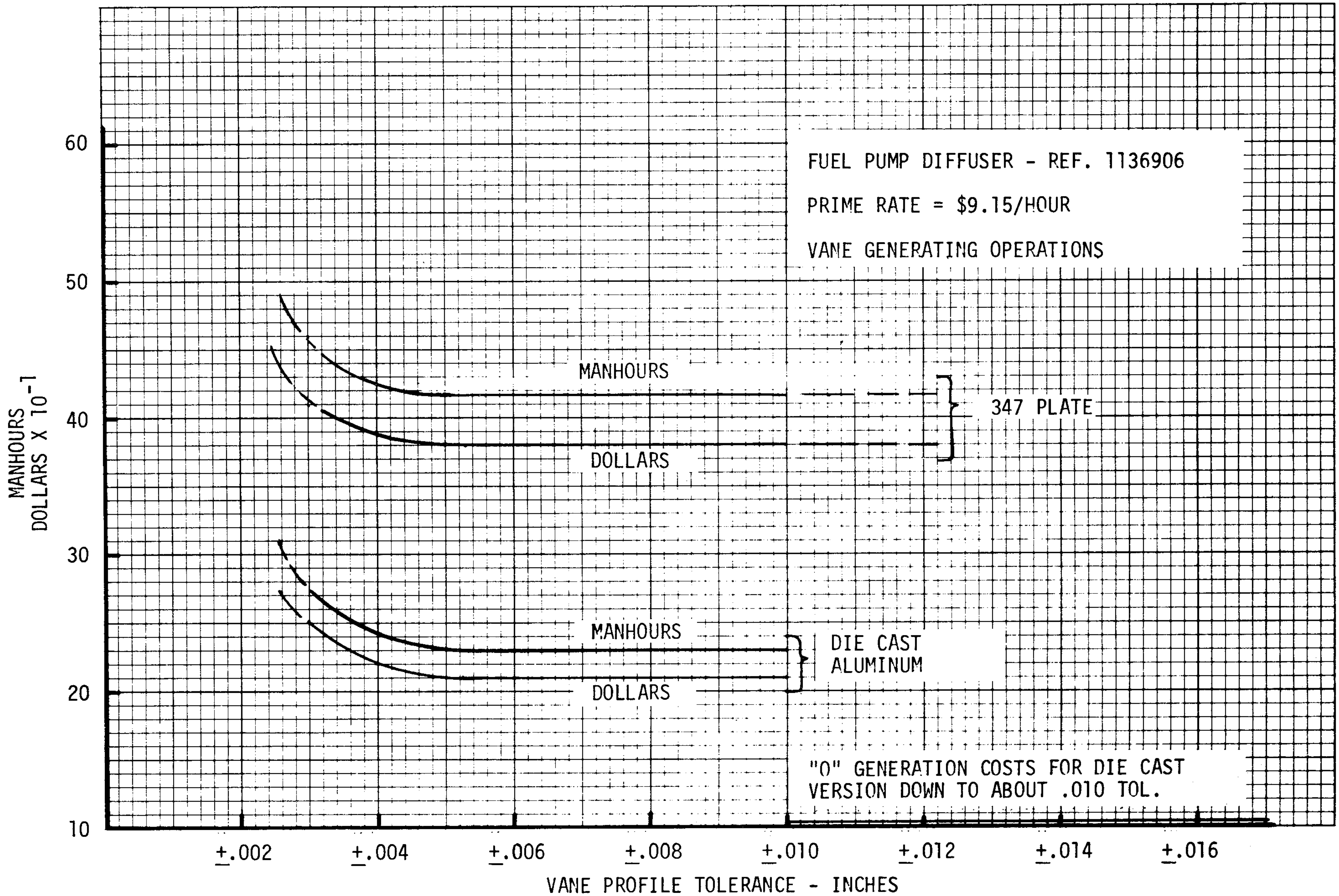


Figure 25. - Cost Effect of Vane Profile Tolerance, Fuel Turbopump Item 29

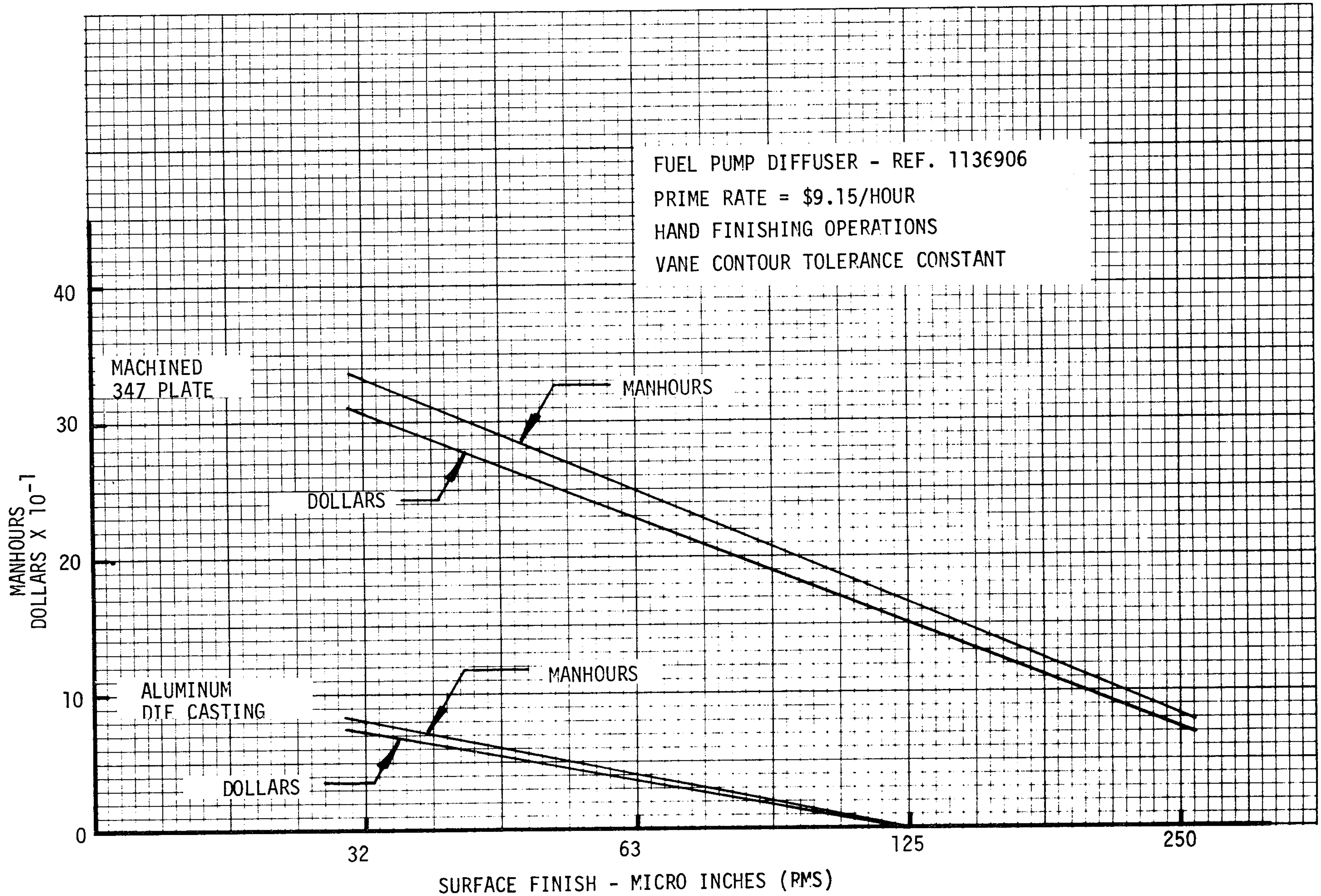


Figure 26. - Cost Effect of Vane Surface Finish, Fuel Turbopump Item 29

version again exhibits the zero cost property at the relatively high roughness value of 125 microin. The machined version would presumably exhibit the same effect if as-machined finishes are acceptable.

c Size Effect

The effect of over-all size upon machining or lumped casting and machining costs are shown on Figure No. 27 for the two diffuser models. Part/feature tolerances are constant at the base case values.

5 Fuel Turbopump Item 30 - Fuel Pump Impeller

a Vane Outside Diameter Tolerance

The effect of vane outside diameter tolerance upon cost of finish turning operations is displayed on Figure No. 28. The primary reason for the lost reduction shown is the reduced tracer lathe set-up time required at the larger tolerance. Quantitative lost data was not obtained at tolerances larger than ±0.010 but discussions with suppliers indicate that no additional reduction could be obtained at tolerances greater than approximately ±0.015. Finish-turning might be eliminated entirely if part-to-part blade height and outside diameter contour tolerances of approximately ±0.03 could be accomplished.

b Vane Profile Tolerance

Figure No. 29 shows the effect of vane profile tolerance, including hub contour tolerance, upon vane generating costs. The very strong (20%) variation in cost is almost entirely a function of the number of cutter replacement/sharpening operations.

c Surface Finish

Figure No. 30 shows the very significant effect of surface finish upon hand-finishing cost for two technological levels of performing the operation. The cost of performance and the finishes obtainable from the sandblast method are both somewhat speculative because none of the suppliers contacted had actually used this method for finishing a machined impeller. It is probable that the vane profile tolerance also would have to be relaxed from the base case value to utilize the sandblast alternative.

6 Fuel Turbopump Item 31 - Fuel Pump Inducer

The cost effects of vane profile tolerance, outside diameter contour tolerance, and surface finish are shown on Figures No. 31 through No. 33. The data are subject to the same limitations and uncertainties described for the fuel pump impeller (Item 30).

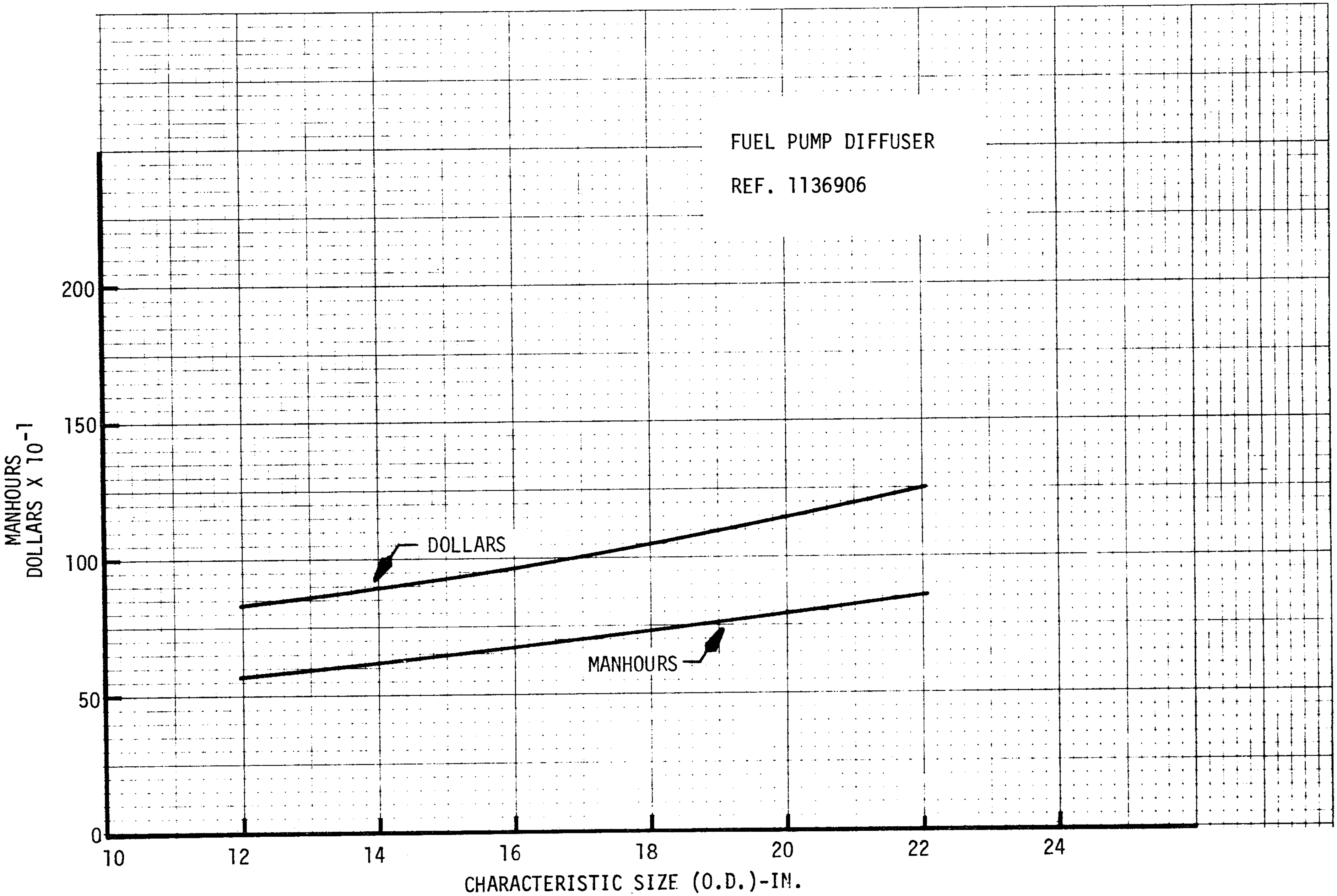


Figure 27. - Cost Effect of Size, Fuel Turbopump Item 29

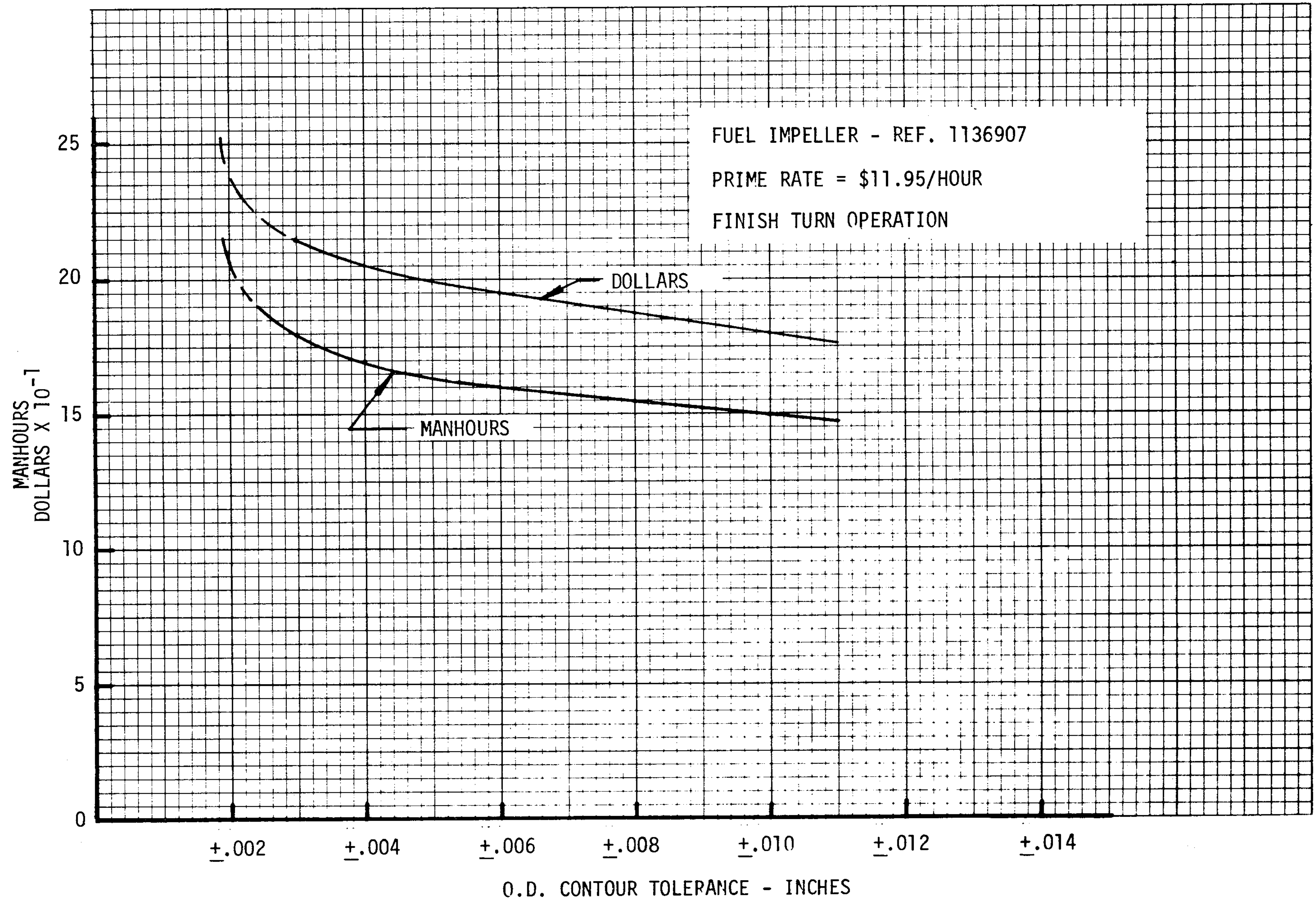


Figure 28. - Cost Effect of Vane Outside Diameter Tolerance, Fuel Turbopump
Item 30

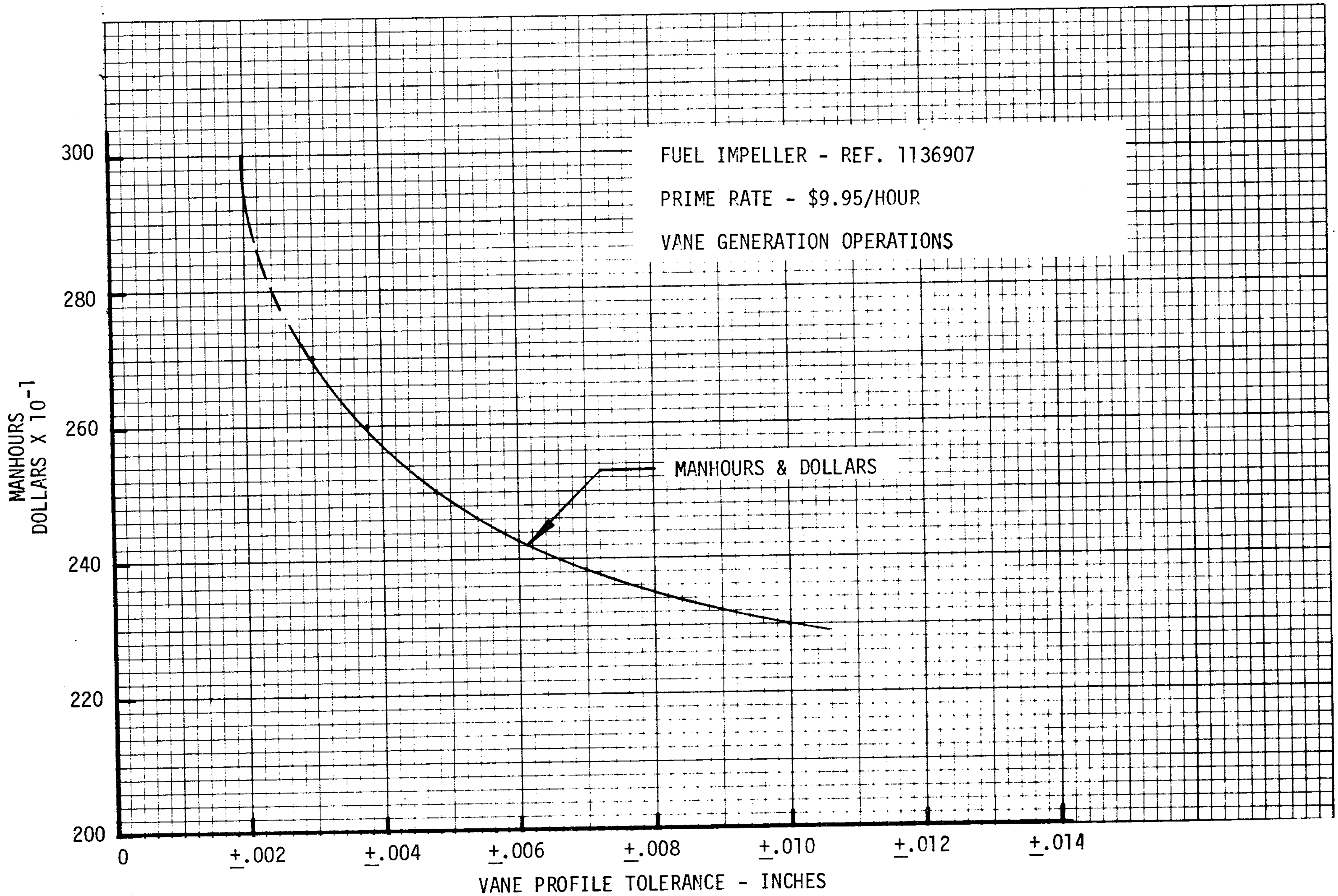


Figure 29. - Cost Effect of Vane Profile Tolerance, Fuel Turbopump Item 30

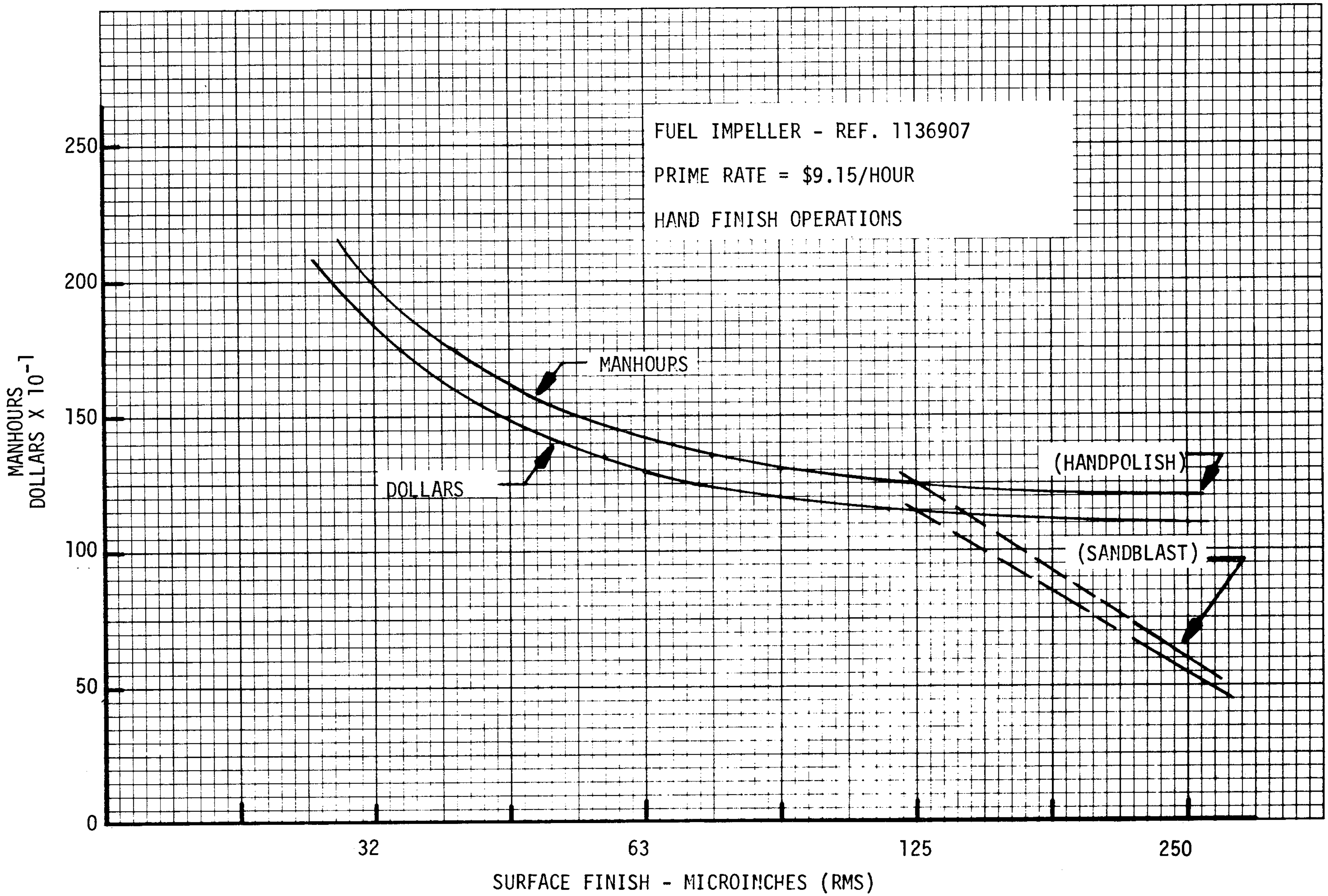


Figure 30. - Cost Effect of Surface Finish, Fuel Turbopump Item 30

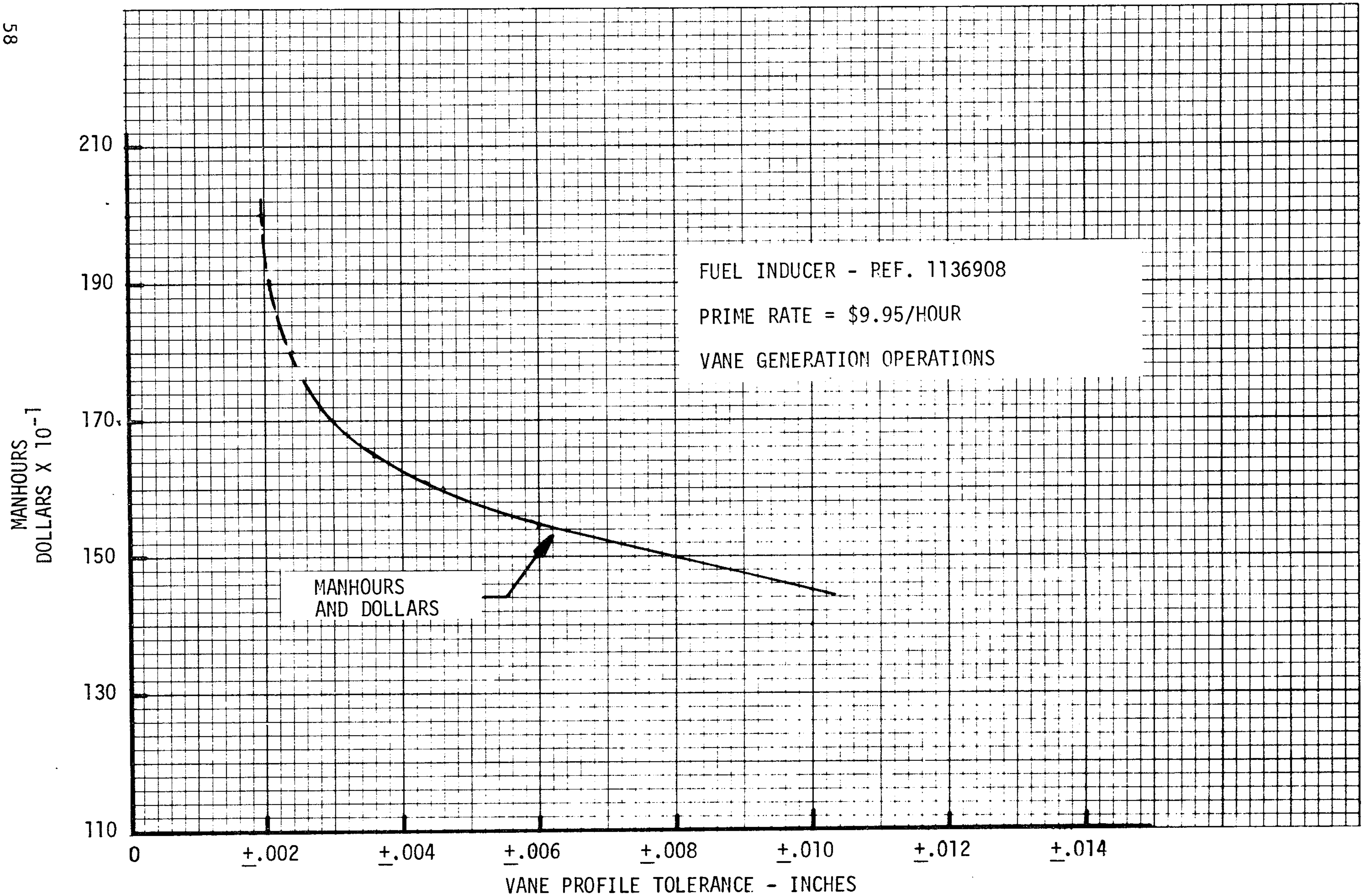


Figure 31. - Cost Effect of Vane Profile Tolerance, Fuel Turbopump Item 31

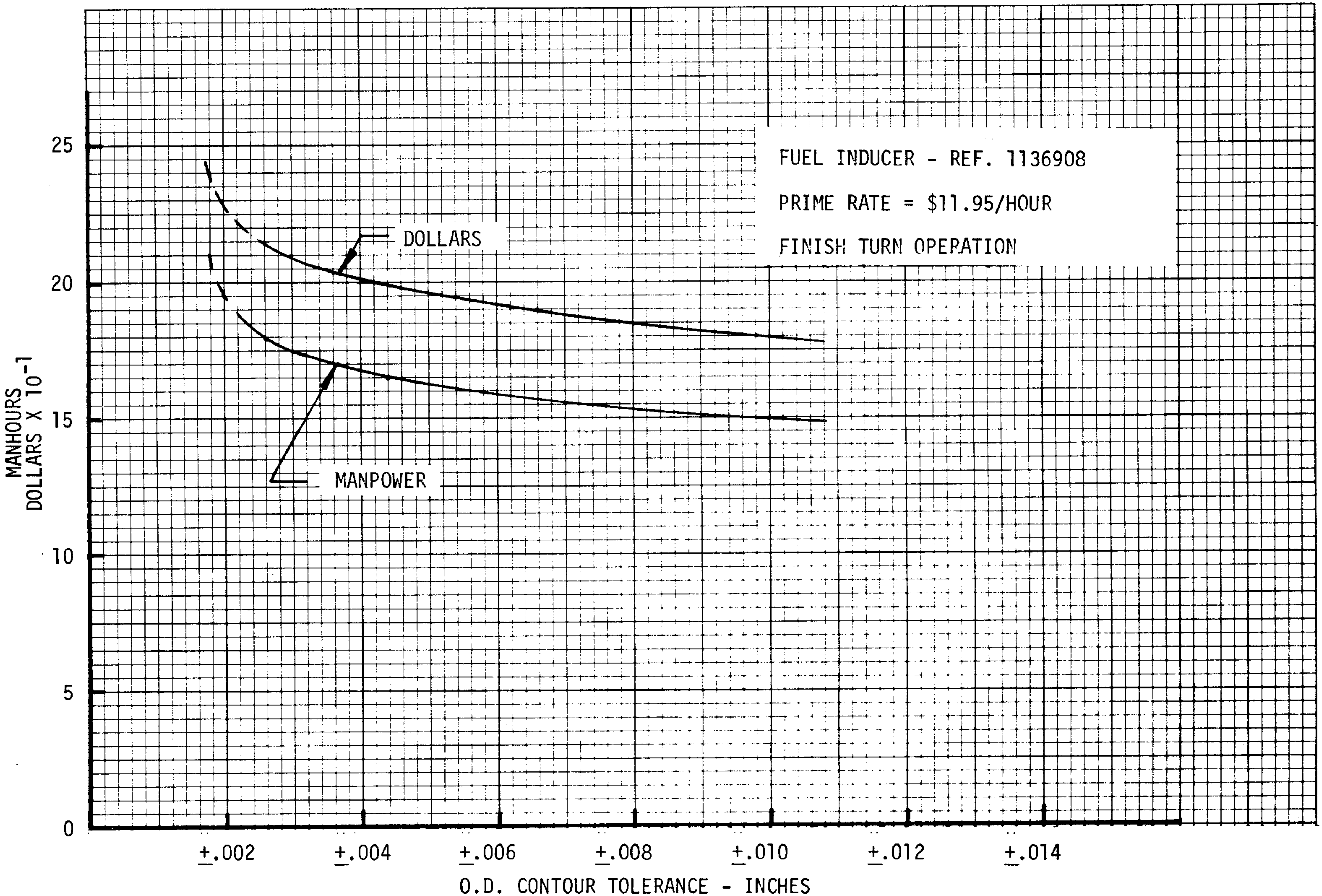


Figure 32. - Cost Effect of Vane Outside Diameter Tolerance, Fuel Turbopump Item 31

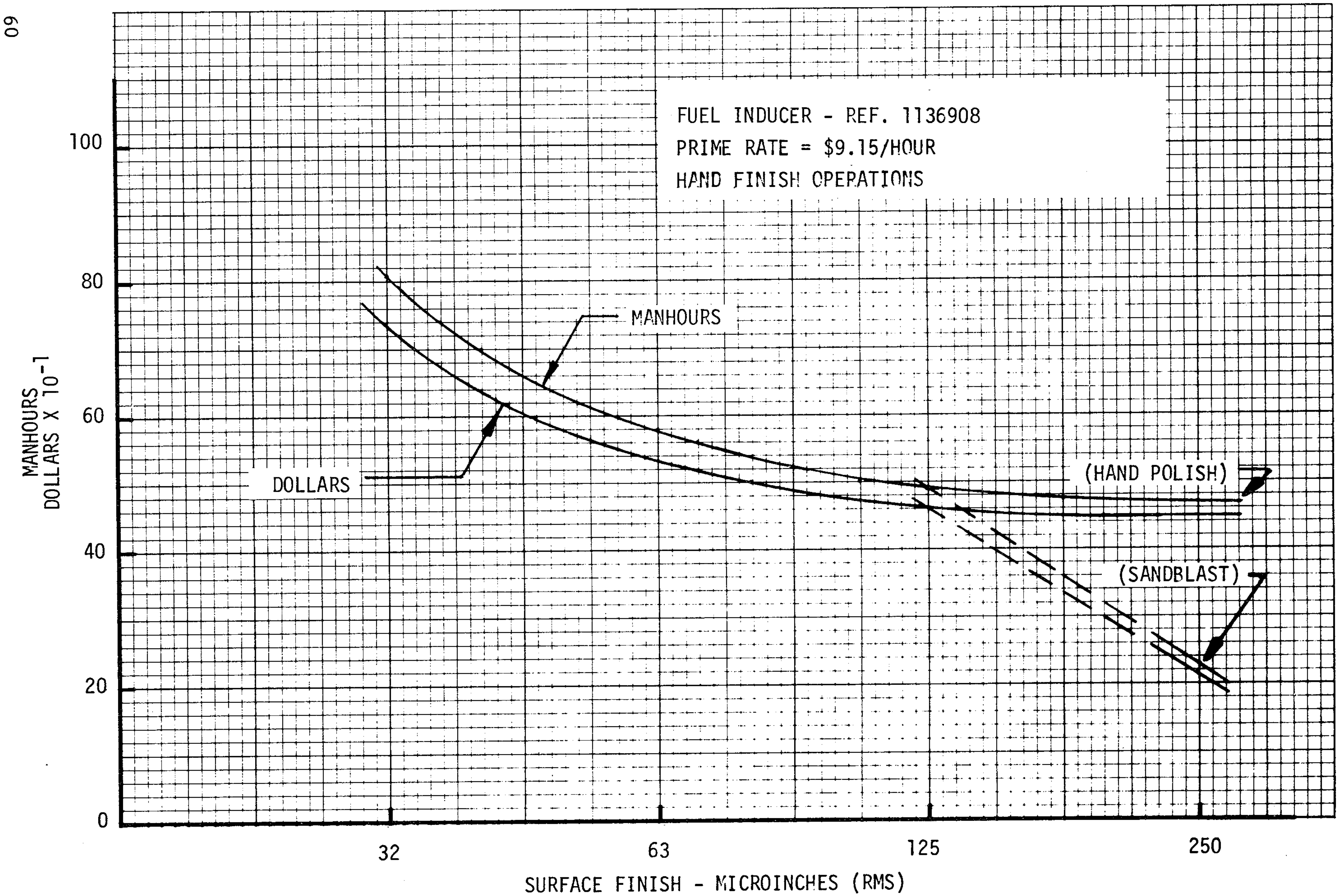


Figure 33. - Cost Effect of Surface Finish, Fuel Turbopump Item 31

7 Fuel Turbopump Item 33 - Fuel Turbine Manifold

a Critical Dimension Tolerance

Figure No. 34 gives the cost effect of critical dimensional tolerance (i.e., tolerances on pilot diameters and axial stacking planes). Machining time reduces rapidly by approximately 12% from ±0.002 to ±0.005 tolerance but little effect is noted at higher tolerances. Inspection time does not vary significantly over the ±0.002 to ±0.005 tolerance range.

b Vane Profile Tolerance

The effect of vane profile tolerance upon cost of generating the vanes is shown on Figure No. 35 for two technological levels of performing the operation. The upper curves are for a fully-machined forged ring with integral machined vanes while the lower curves represent a model where integral vanes are first cast to some intermediate tolerance and then machined to final tolerance. A third (as-cast) version is implied but requires that vane profile tolerance be approximately ±0.010. A fixed casting prime cost of $1,700 or ring forging prime cost of $400 must be added to the appropriate curve value to compare alternative part production costs.

8 Fuel Turbopump Item 34 - Fuel Pump Housing

a Casting Tolerance

Figure No. 36 shows that the cost effect of casting tolerance is almost entirely dependent upon scrap rate. The base case tolerance of ±0.030 on flow passage and critical structural features results in a dimensional defect scrap rate of approximately 4% which increases to approximately 15% at ±0.020 tolerance and approaches zero at ±0.050 tolerance.

b Critical Dimension Tolerance

The effect of critical dimensional tolerances upon final turning costs is given on Figure No. 37. Pilot diameter and inside diameter contour tolerances were varied together in the ratio shown to obtain the data and the effects are therefore inseparable.

9 Fuel Turbopump Assembly

a Stacking Dimension Tolerance

Assembly costs in terms of assembly labor manhours and total assembly net dollars versus critical axial stacking

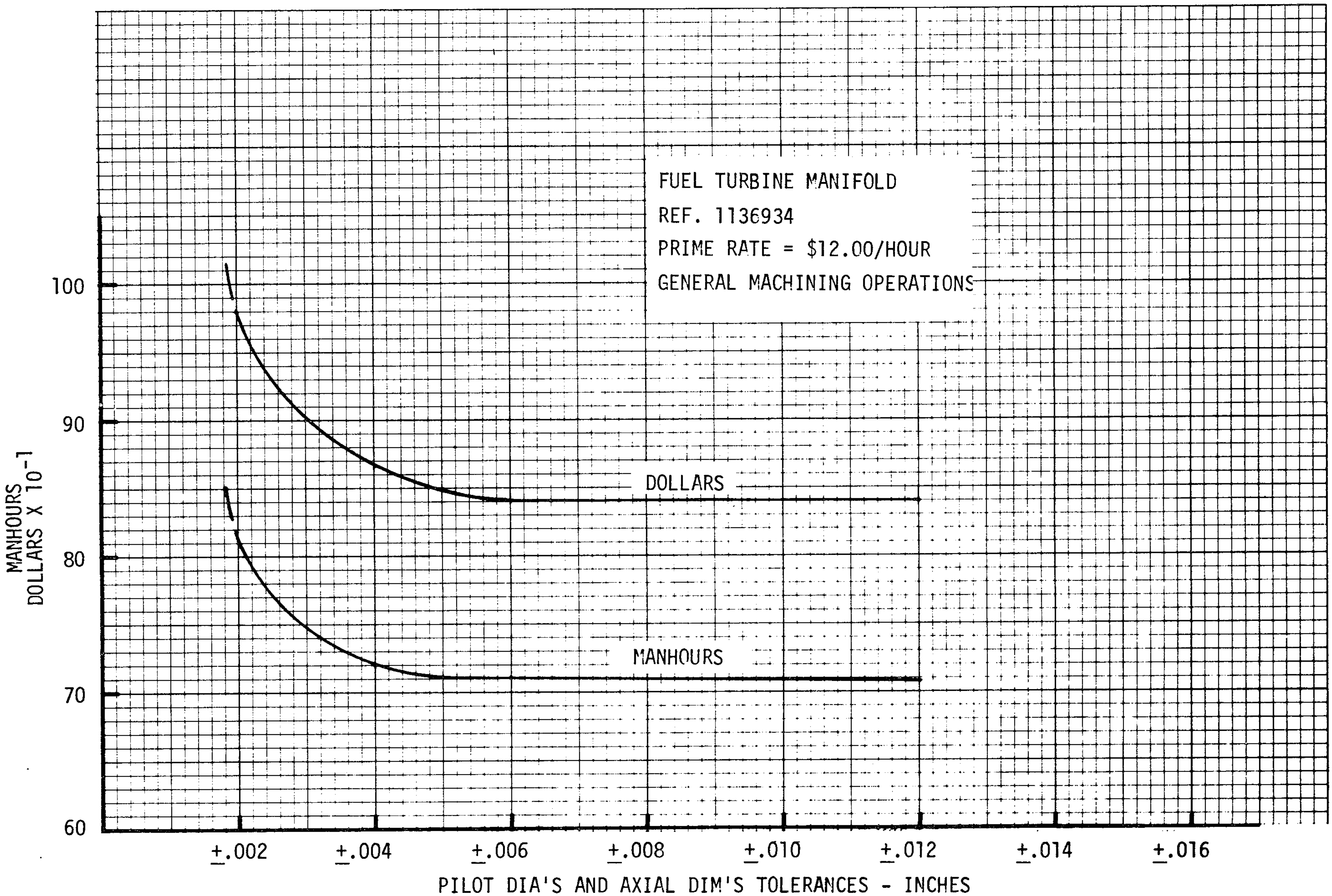


Figure 34. - Cost Effect of Critical Dimension Tolerance, Fuel Turbopump Item 33

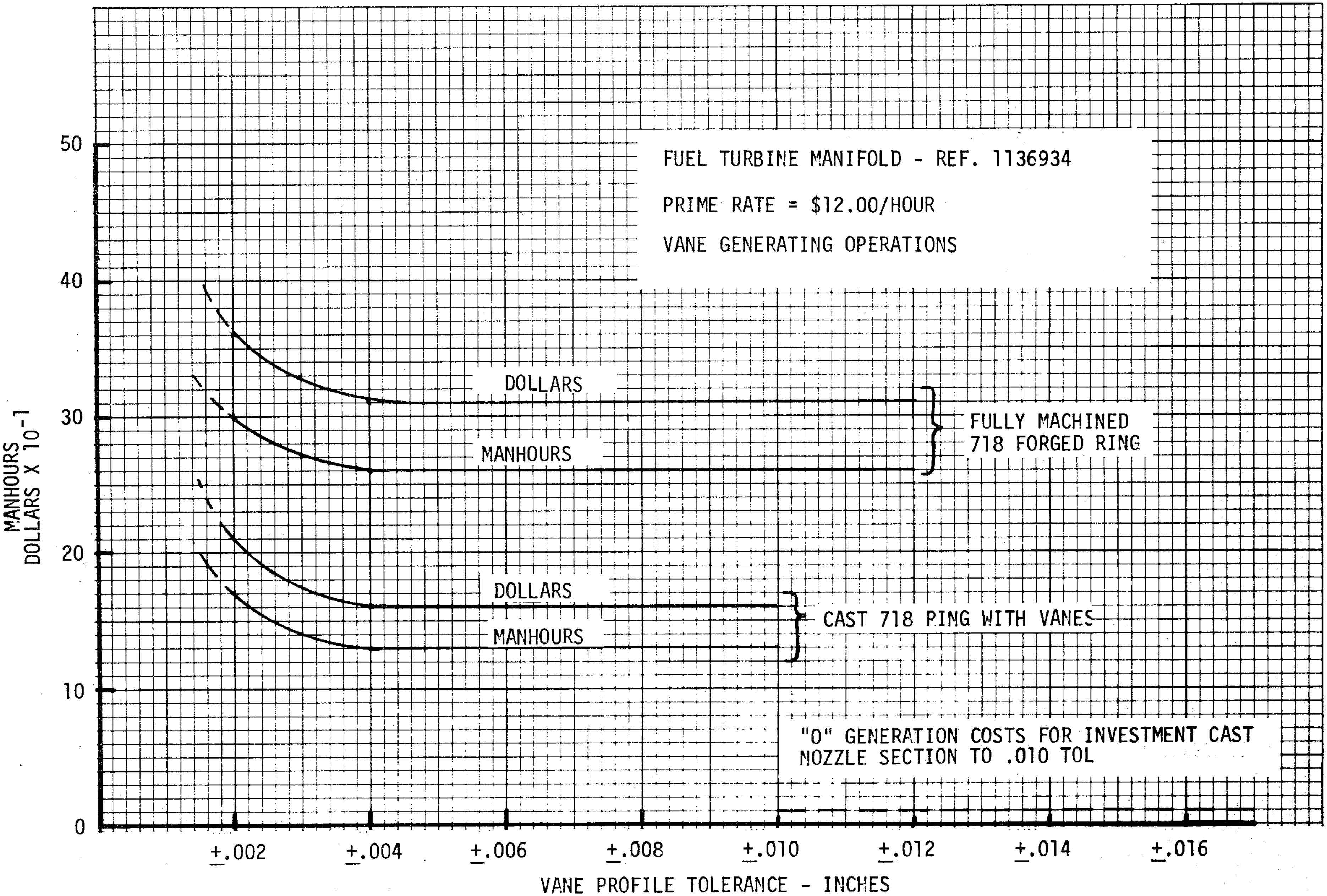


Figure 35. - Cost Effect of Vane Profile Tolerance, Fuel Turbopump Item 33

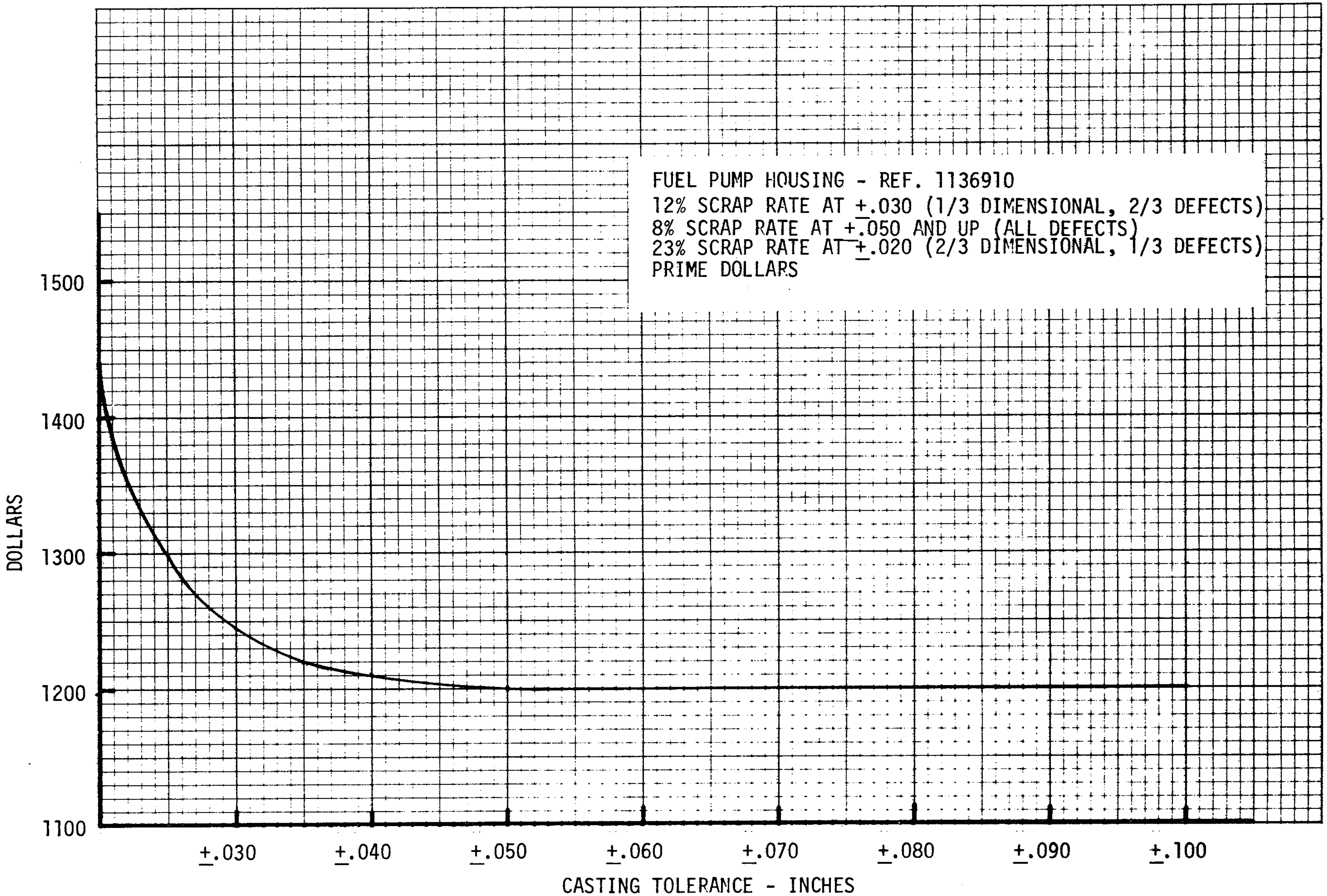


Figure 36. - Cost Effect of Casting Tolerance, Fuel Turbopump Item 34

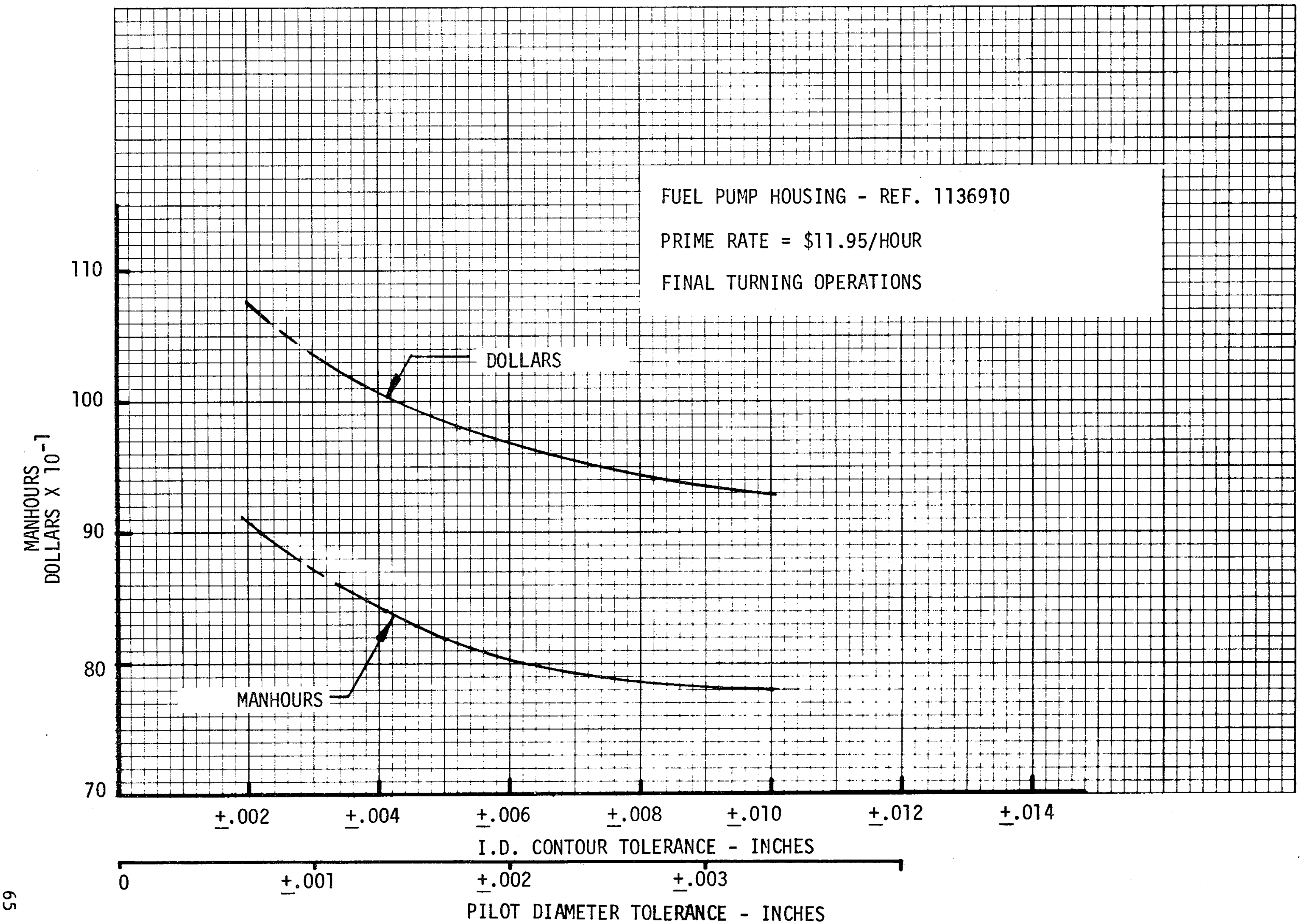


Figure 37. - Cost Effect of Pilot and Inside Diameter Contour Tolerance,

dimension tolerance are shown on Figure No. 38. Tolerances are assumed to be distributed equally for the several parts affecting pump and turbine vane and thrust balancer clearances. Assembly cost differences are totally attributable to the additional assembly operations required to custom-fit spacers/shims for larger tolerance parts.

<u>b</u> Size Effect

The cost versus size data shown on Figures No. 16, No. 20, No. 24 and No. 27, along with similar data for all other major turbopump subcomponents were utilized to produce the turbopump level size effect data for the over-all machine. These data are displayed on Figure No. 39 directly as a function of required NPSH. Only net costs in dollars are shown because no single hourly rate is applicable to all subcomponents.

<u>10</u> LOX Turbopump Item 17 - LOX Pump Housing

<u>a</u> Casting Tolerance

Figure No. 40 shows the cost effect of casting tolerance. The cost of the parts is almost entirely a function of scrap rate. The typical tolerance of ± 0.030 on flow passage and structural features results in a scrap rate of approximately 12%; split one-third for dimensional defects and two-thirds for casting flaws such as porosity and inclusions. Only the dimensional defect rate is affected by the casting tolerance, with the rate increasing four times at a tolerance of ± 0.020 and decreasing to zero at approximately ± 0.050. It is possible that the scrap rate curve knee could be moved to lower tolerance levels by investment casting techniques but at a sharply increased cost because the technique would require considerable development for this size machinery.

<u>b</u> Surface Finish

Figures No. 41 and No. 42 show the cost effect of surface finish requirements for general machining and hand finishing operations. The reduction in costs shown would flatten dramatically if extended to higher roughness values. At a roughness of approximately 250, general machining time is dictated by dimensional tolerance and hand-finishing becomes a simple deburring operation to remove sharp edges.

<u>c</u> Critical Dimension Tolerance

Figure No. 43 and 44 gives the cost effect of critical dimensional tolerances such as the tolerances on pilot diameters, axial stacking planes, and bearing bores. Machining time reduces rapidly by approximately 20% from ± 0.0005 to ± 0.003 tolerance, but little effect is noted at higher tolerances. Inspection time decreases linearly by

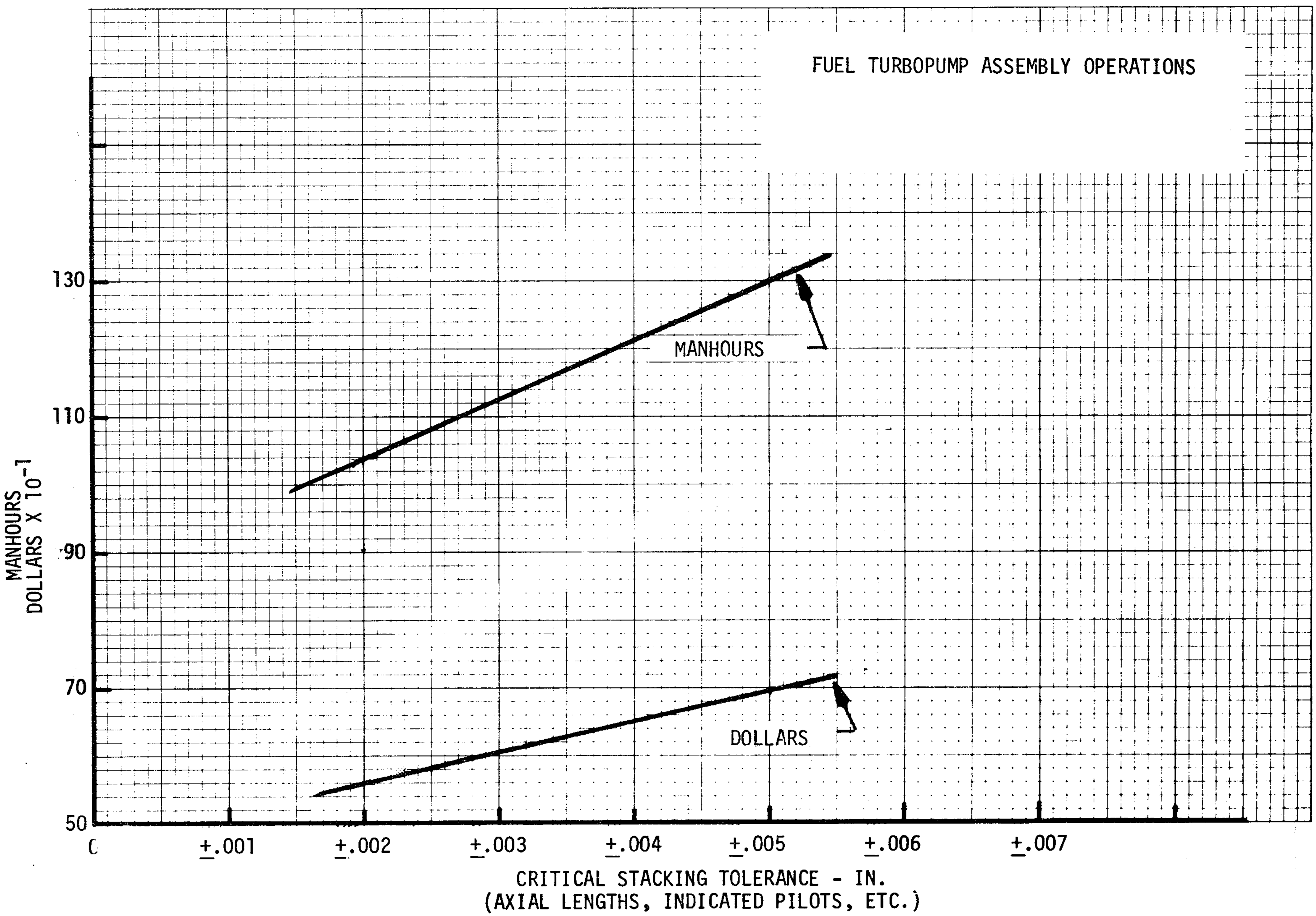


Figure 38. - Cost Effect of Stacking Dimension Tolerance, Fuel Turbopump Assembly

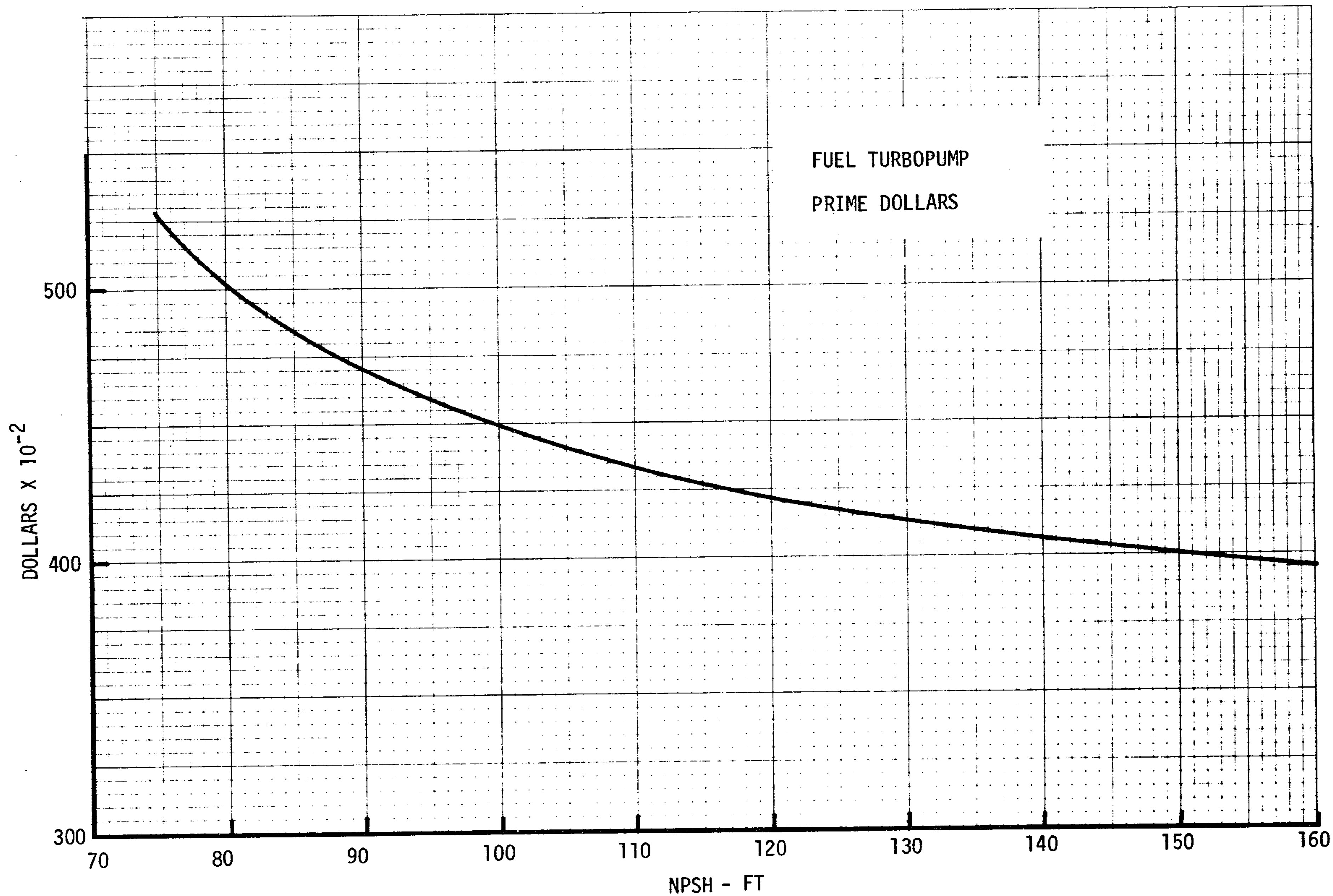


Figure 39. - Cost Effect of NPSH/Size, Fuel Turbopump Assembly

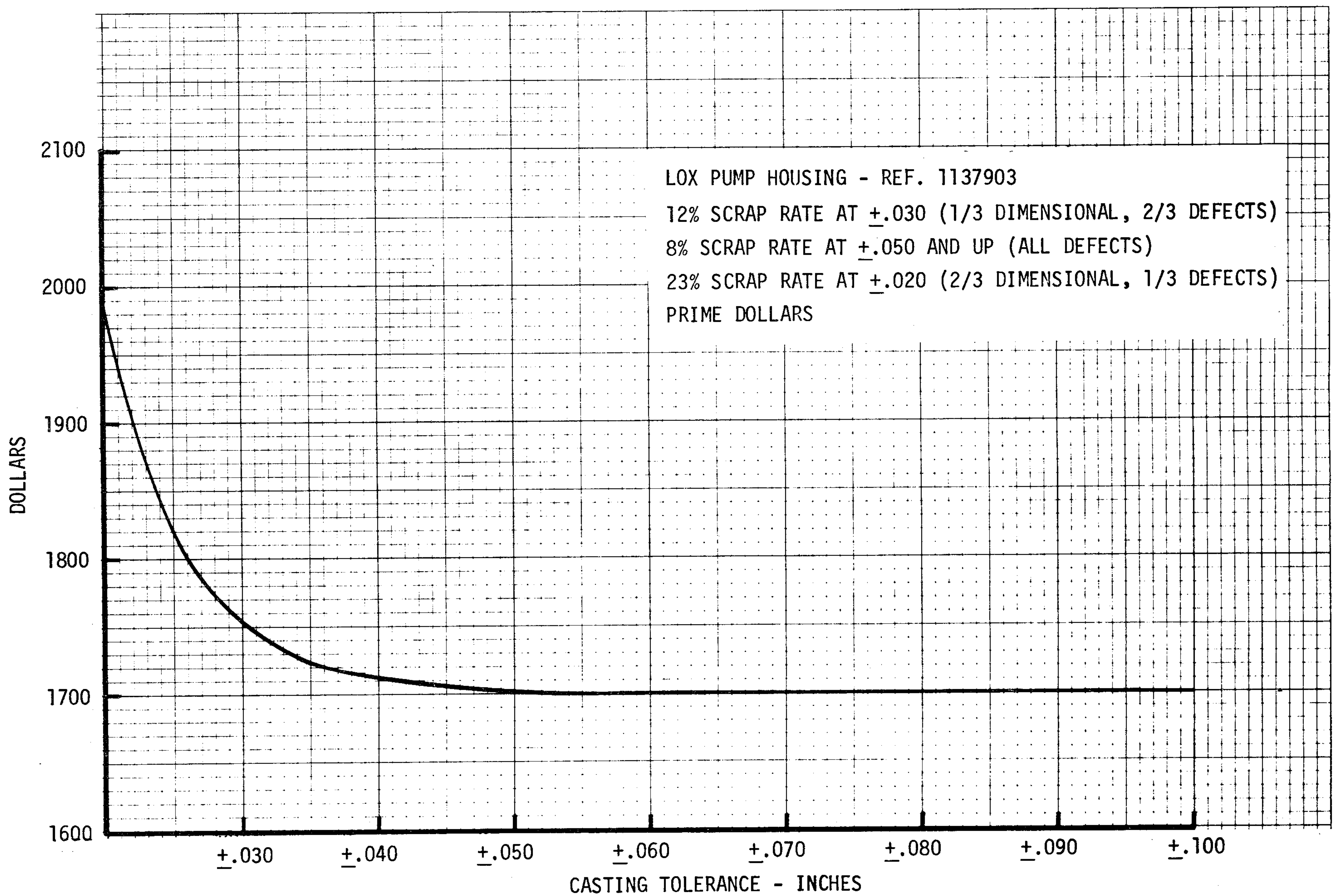


Figure 40. - Cost Effect of Casting Tolerance, LOX Turbopump Item 17

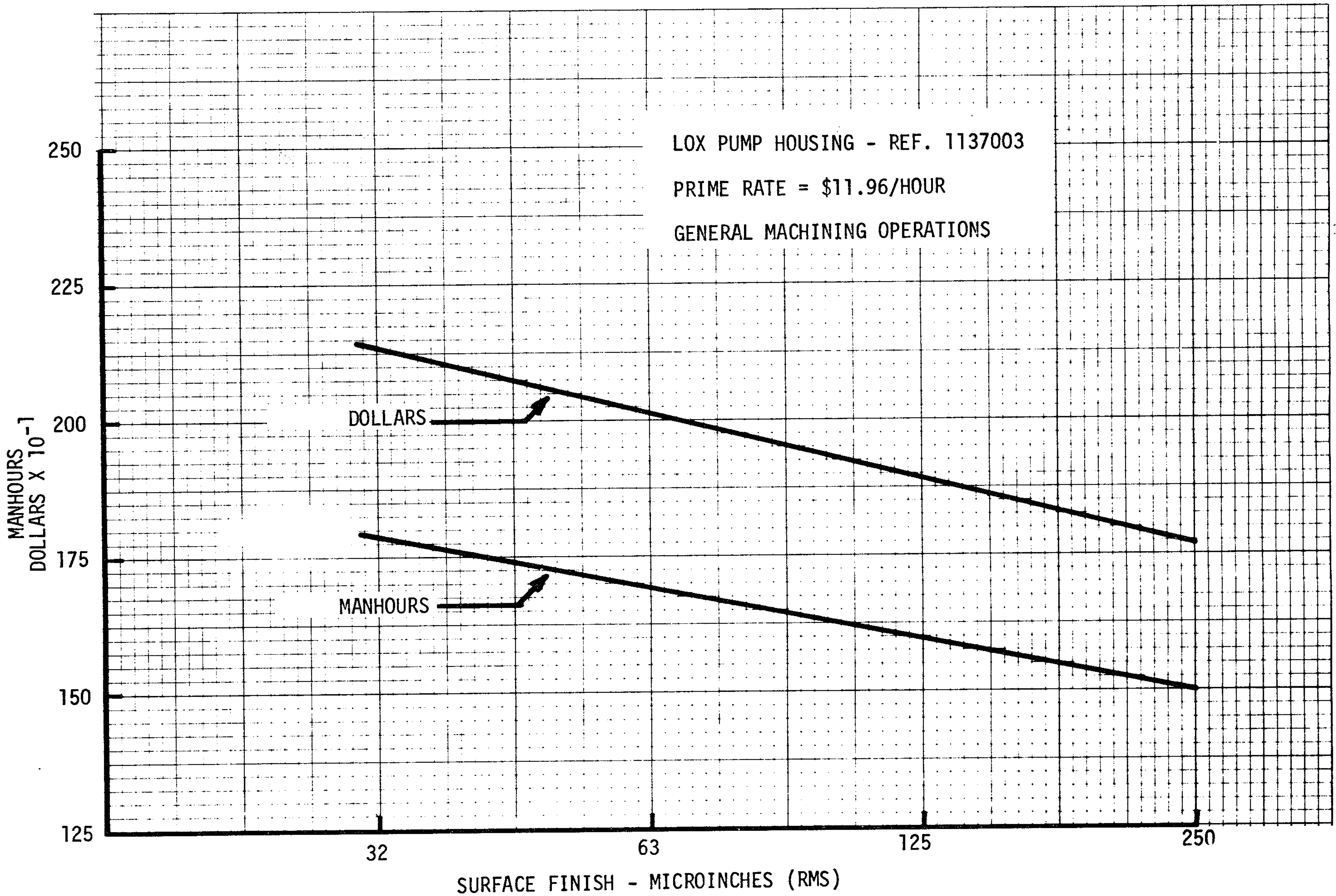


Figure 41. - Cost Effect of Surface Finish (General Machining), LOX Turbopump Item 17

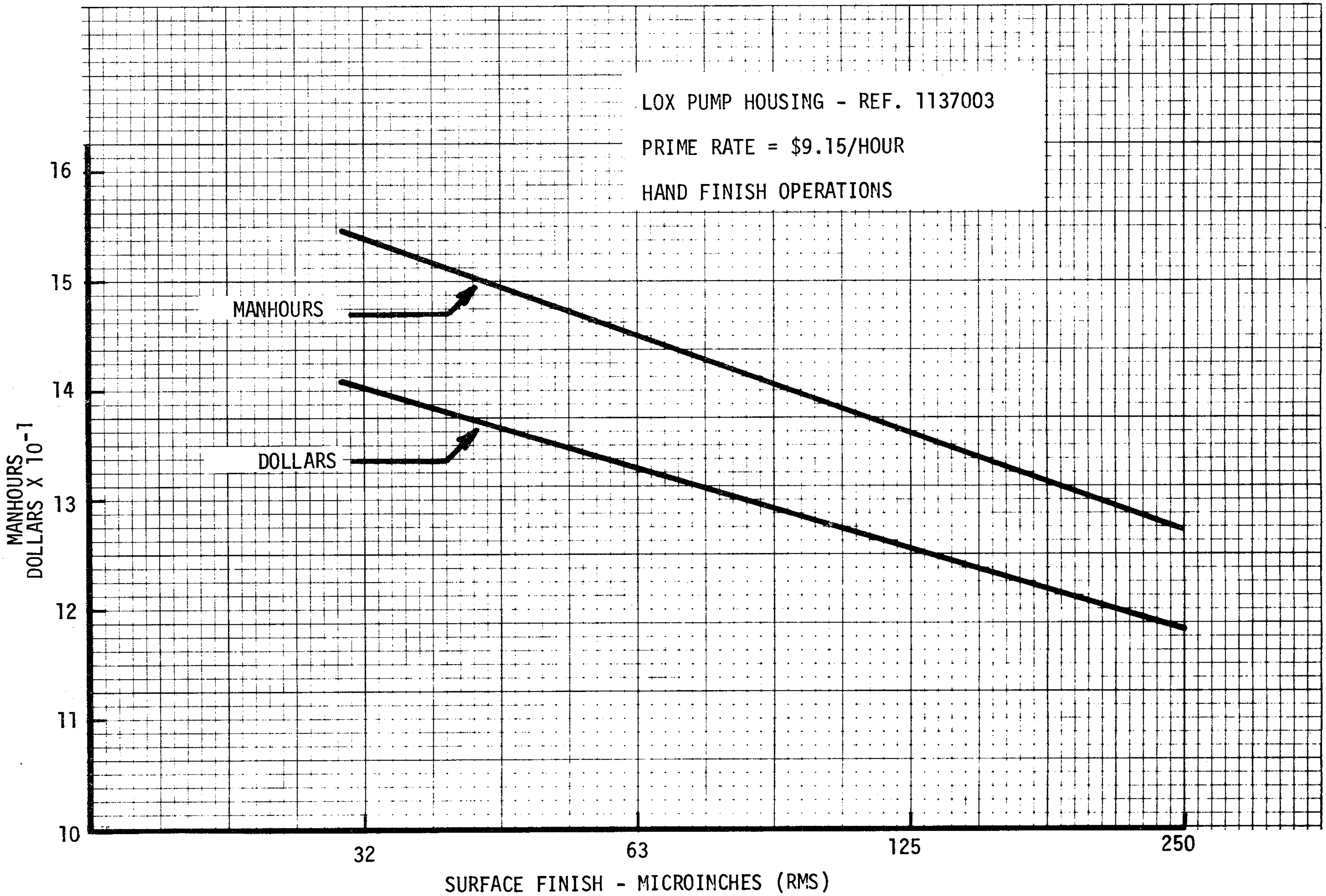


Figure 42. - Cost Effect of Surface Finish (Hand-Finish), LOX Turbopump Item 17

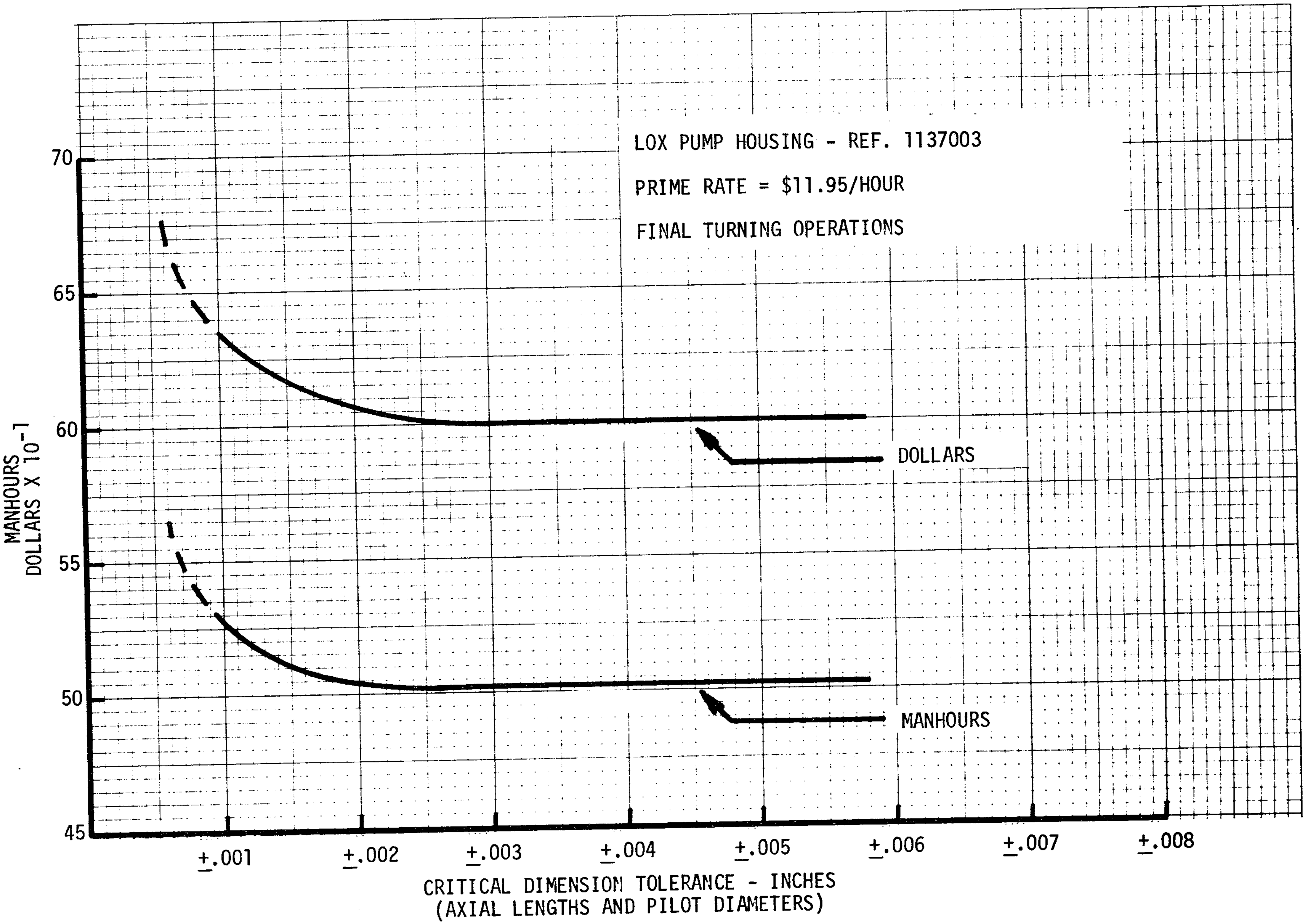


Figure 43. - Cost Effect of Critical Dimension/Tolerance, LOX Turbopump Item 17

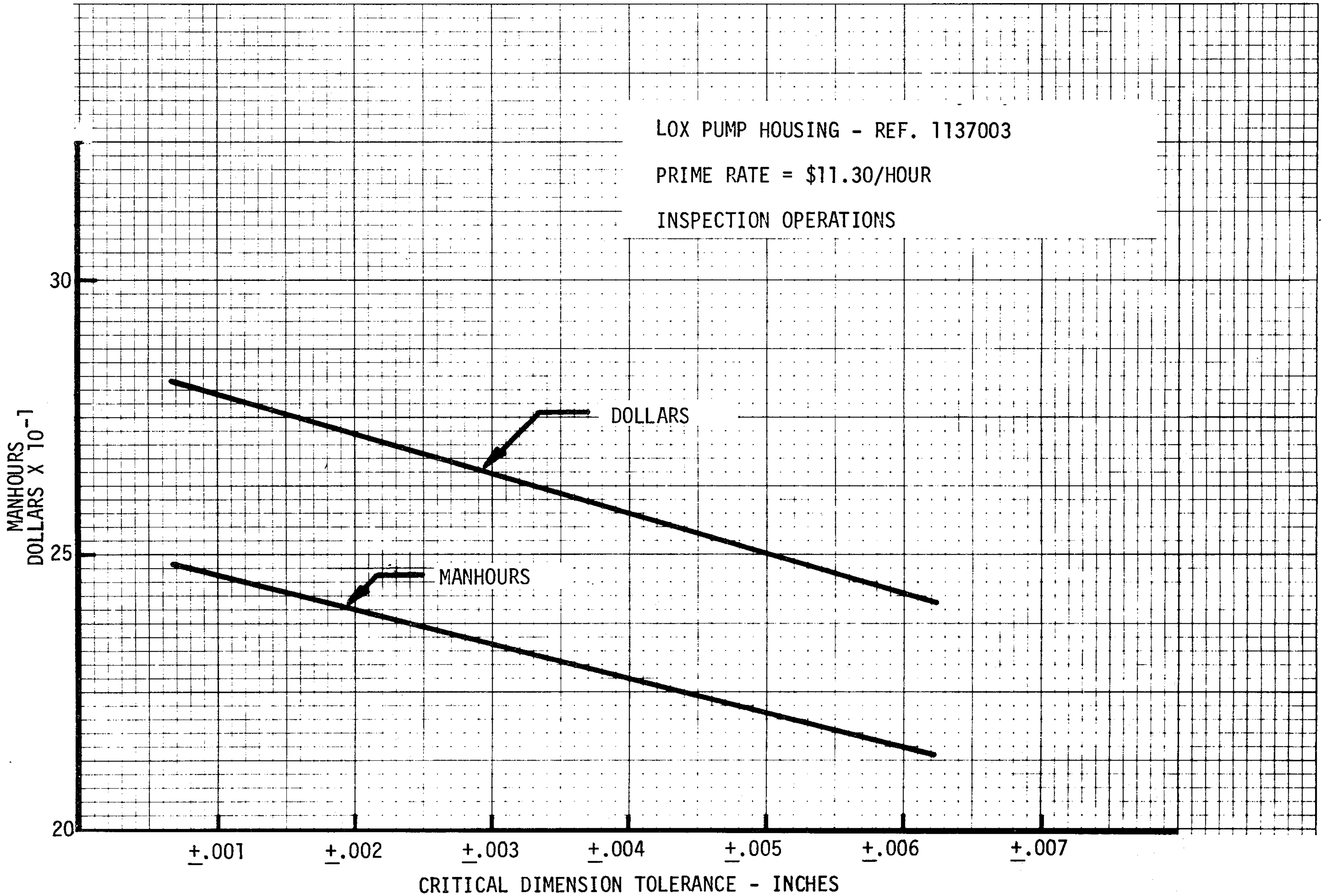


Figure 44. - Cost Effect of Critical Dimension Tolerance, LOX Turbopump Item 17

25% over the range from ±0.0005 to ±0.010 tolerance, but the plots are terminated at approximately ±0.005 to ±0.006 where interference loads in the pilot flanges become excessive.

d Size Effect

Figure No. 45 shows the cost effects of over-all size for the casting and lumped machining operations at the base case tolerances. Combinations at different tolerances can be scaled directly using these data.

11 LOX Turbopump Item 19 - LOX Pump Impeller

a Vane Profile Tolerance

Figure No. 46 shows the effect of vane profile tolerance upon casting costs for two technological levels. Both methods are subject to rejection rate effects similar to those previously discussed for the pump housings.

b Seal Diameter Tolerance

The effect of seal diameter tolerance upon final turning costs is displayed on Figure No. 47. The effect of the alternative technology (investment casting) would far overshadow the cost reductions because of tolerance relaxation, but at a prohibitively large tolerance from a performance standpoint.

c Surface Finish

Figure No. 48 shows the very significant effect of surface finish upon hand-finishing cost for two technological levels of performing the operation. As was the case with the fully-machined fuel impeller, the cost of performance and the finishes obtainable from the sandblast method are both somewhat speculative because none of the suppliers contacted had actually used this method of finishing a high performance impeller. It is probable that the vane profile tolerance also would have to be relaxed from the base case value to utilize the sandblast alternative.

d Size Effect

The effect of over-all size upon lumped casting and machining operations is shown on Figure No. 49. All other requirements are constant at the base case values.

12 LOX Turbopump Item 20 - LOX Pump Inducer

The cost effects of vane profile tolerance, outside diameter contour tolerance, surface finish and size are shown on

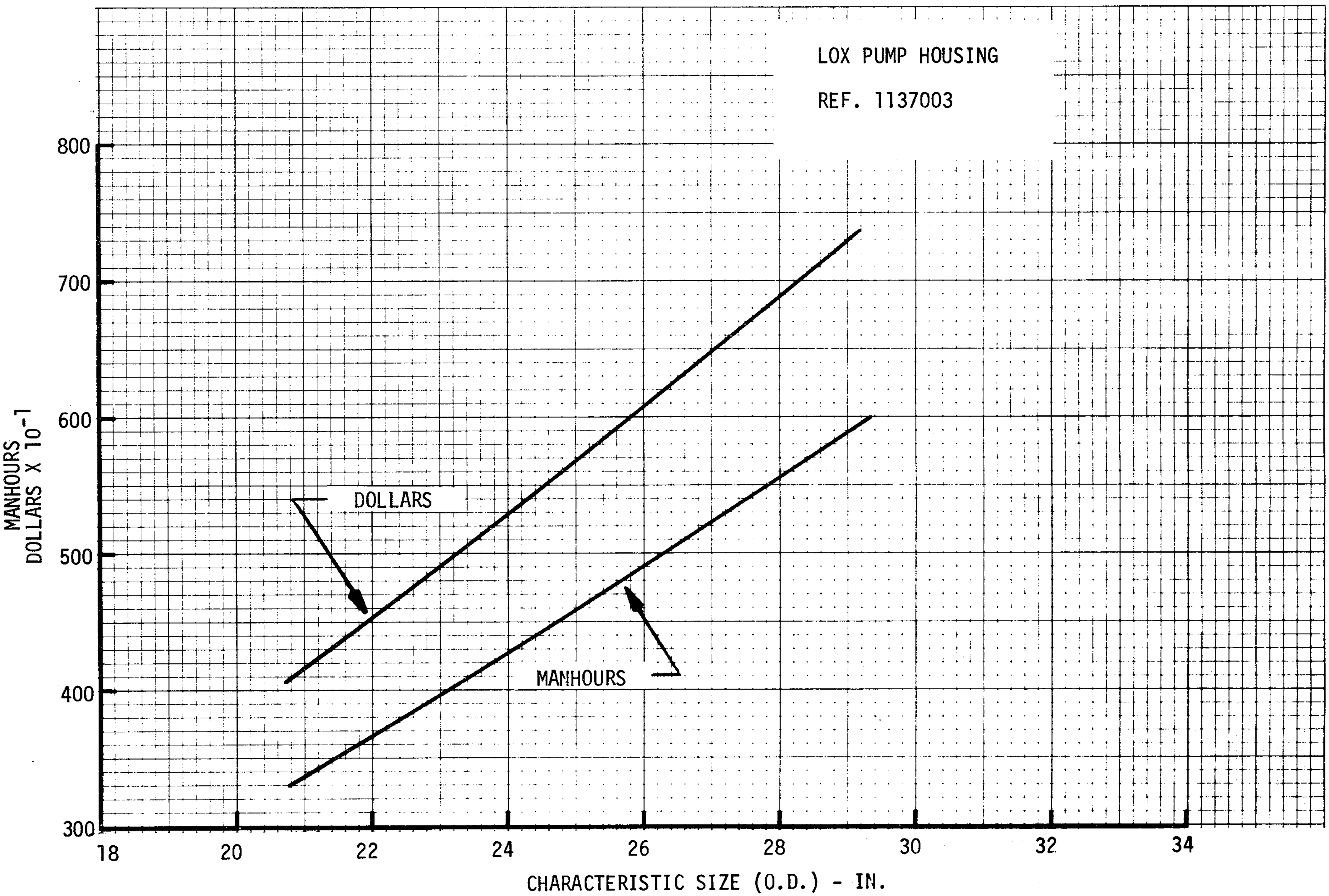


Figure 45. - Cost Effect of Size, LOX Turbopump Item 17

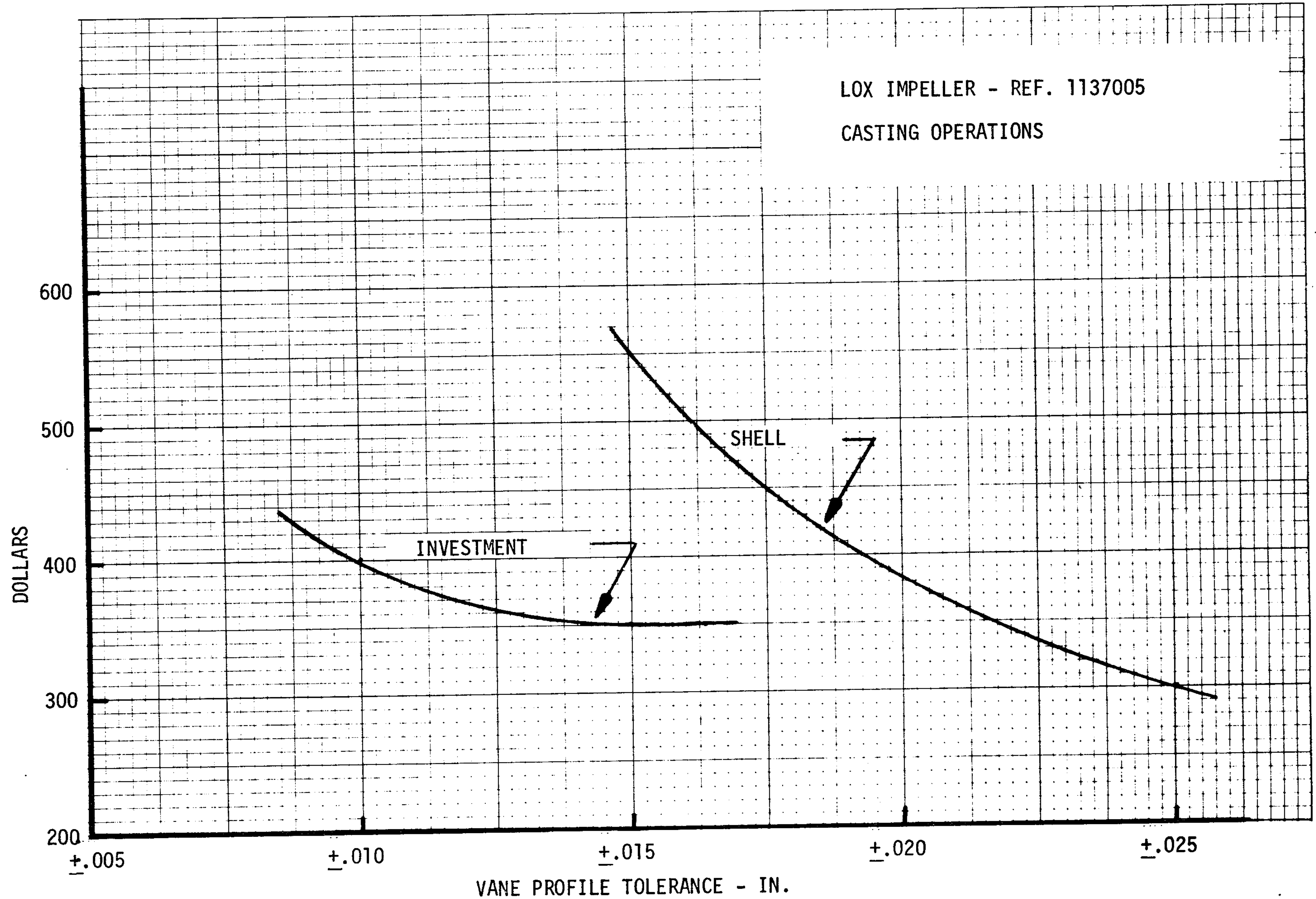


Figure 46. - Cost Effect of Vane Profile Tolerance, LOX Turbopump Item 19

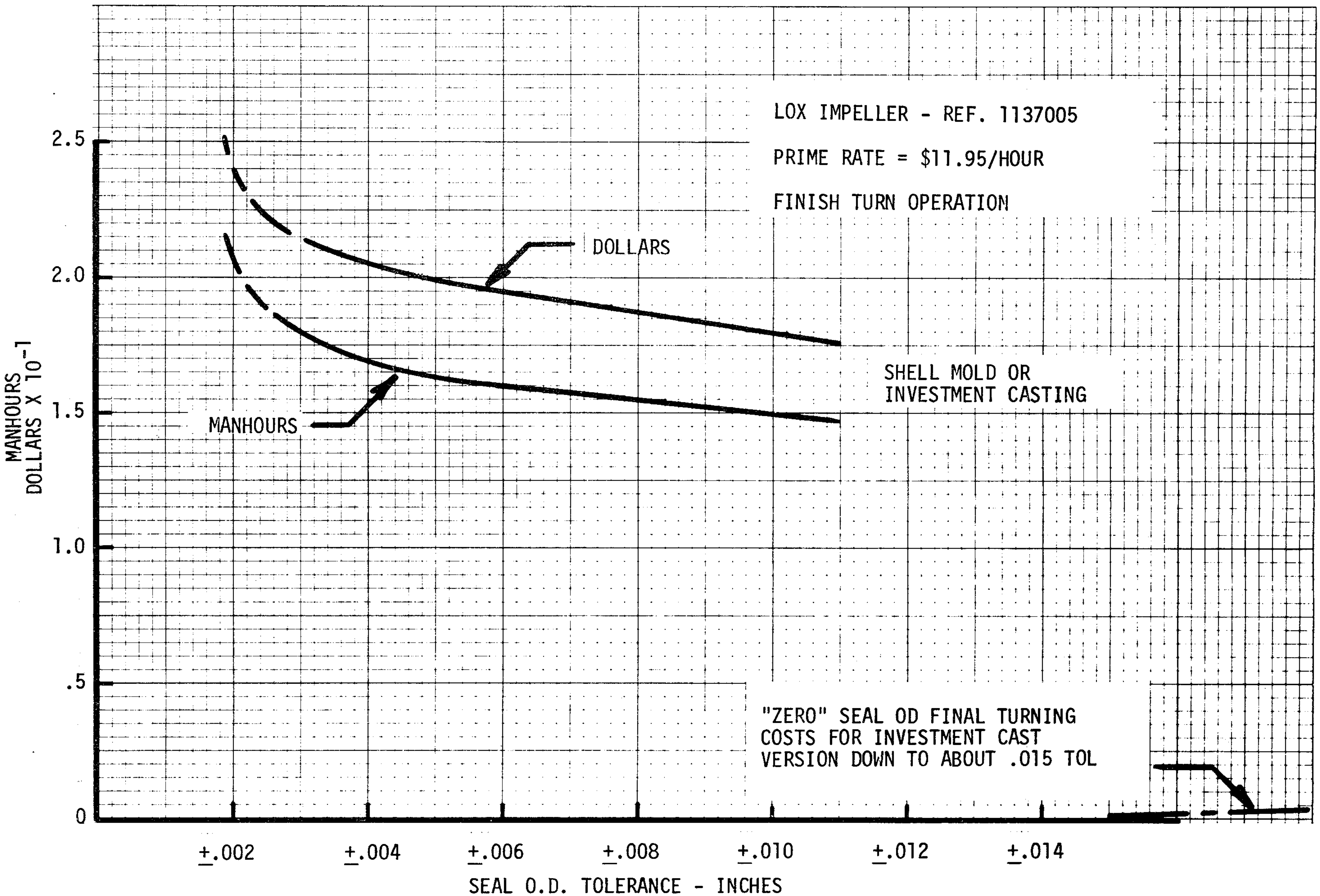


Figure 47. - Cost Effect of Seal Outside Diameter Tolerance, LOX Turbopump Item 19

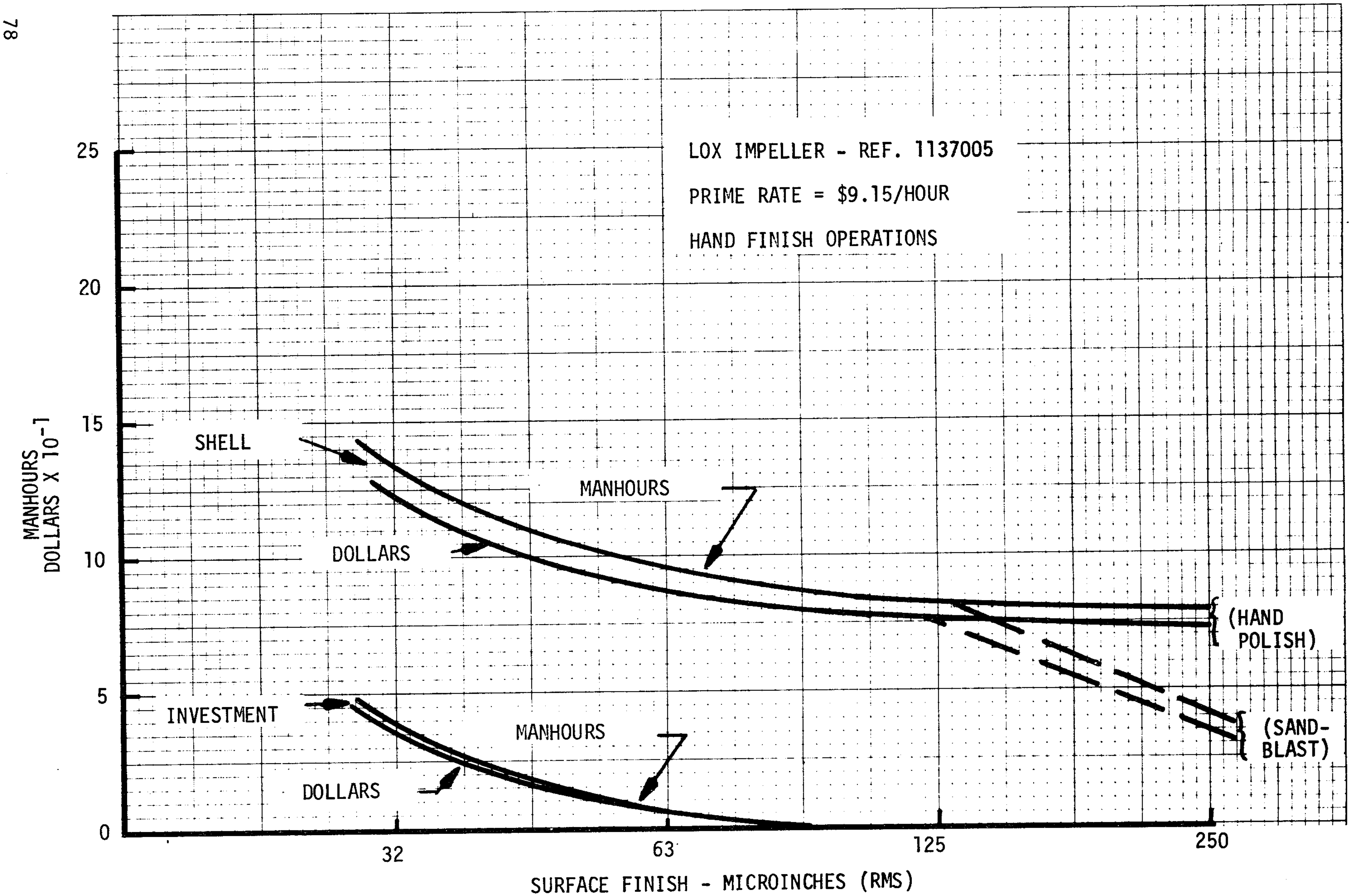


Figure 48. - Cost Effect of Surface Finish, LOX Turbopump Item 19

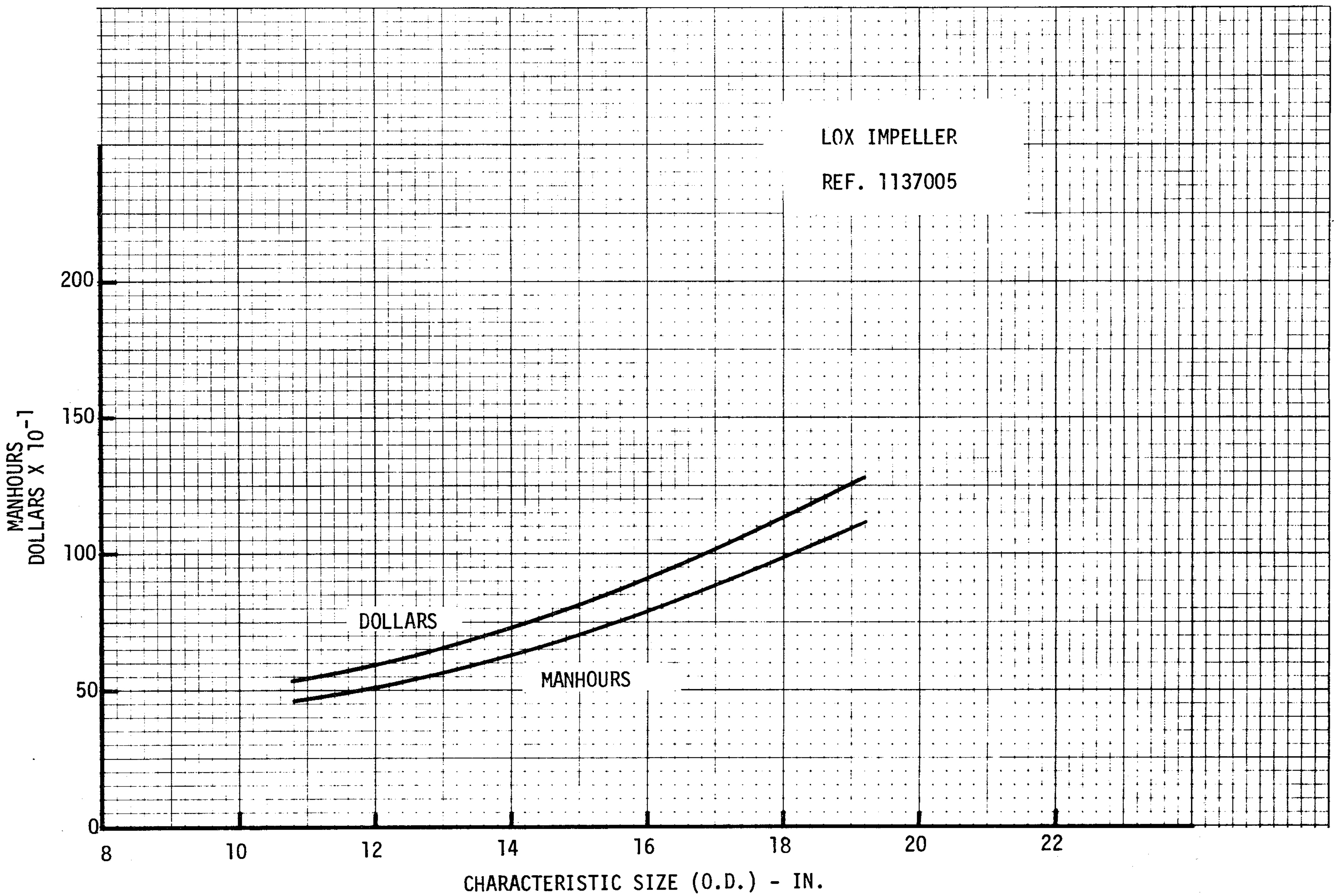


Figure 49. - Cost Effect of Size, LOX Turbopump Item 19

Figures No. 50 through No. 53 for fully-machined, cast and cast and machined inducers. The data for the machined version are subject to the same limitations and uncertainties described for the fuel pump impeller and inducer. The casting costs are relatively invariant over the range of tolerances investigated because of the simple helicoidal shape assumed. More complex (cambered) vane shapes would probably result in a variable rejection rate as a function of tolerance but no quantitative data were obtained.

13 LOX Turbopump Item 25 - LOX Pump Inlet Adapter

a Casting Tolerance

Figure No. 54 shows the cost effect of casting tolerance. The change in cost is totally a function of dimensional rejection rate for this part because material strength is not critical and casting flaws can be tolerated.

b Critical Bore and Pilot Diameter Tolerance

The effect of critical dimensional tolerances upon final turning costs is given on Figure No. 55. Pilot diameter and bore tolerances were varied together in the ratio shown to obtain the data and the effects are therefore inseparable.

c Surface Finish

No appreciable cost differences were noted over the 63 microin. to 250 microin. roughness range investigated.

14 LOX Turbopump Item 26 - LOX Turbine Rotor

a General Dimensional Tolerance

The cost effect of general dimensional tolerances (i.e., outside diameter and axial length) is displayed on Figure No. 56. The rather small (4% to 5%) cost reduction shown occurs in the range from ±0.001 to ±0.003 with no significant improvement from ±0.003 out to ±0.005.

b Surface Finish

Figure No. 57 shows a significant (8% to 10%) cost effect of surface finish over the range from 32 microin. to 250 microin. roughness, but the effect would flatten at approximately 250 250 microin. when dimensional requirements limit machining time and hand work in the blading is eliminated. Significant further improvement could be obtained if as-forged/cast or as-forged/cast and sandblasted dimensional variations could be tolerated on the disc surfaces.

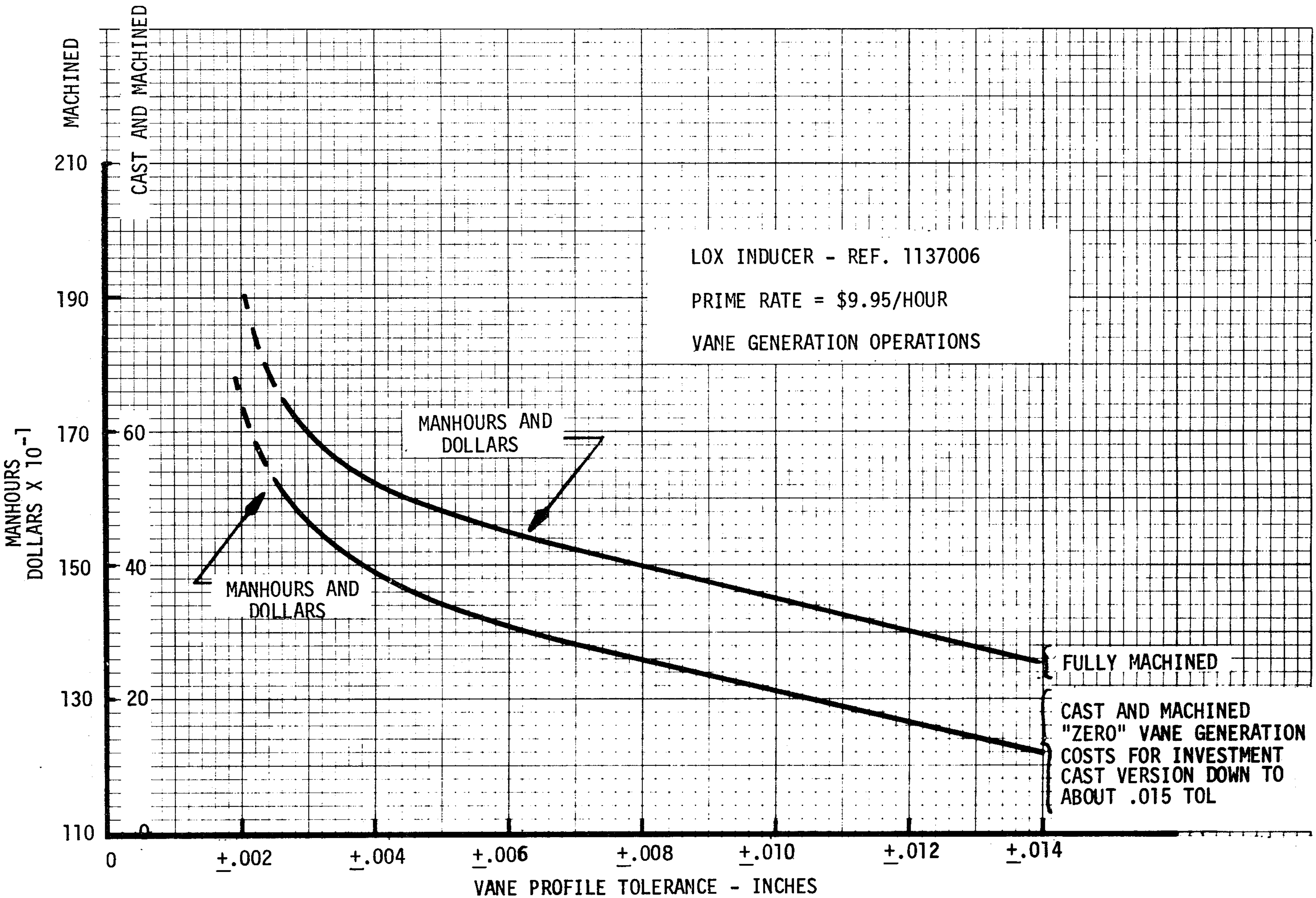


Figure 50. - Cost Effect of Vane Profile Tolerance, LOX Turbopump Item 20

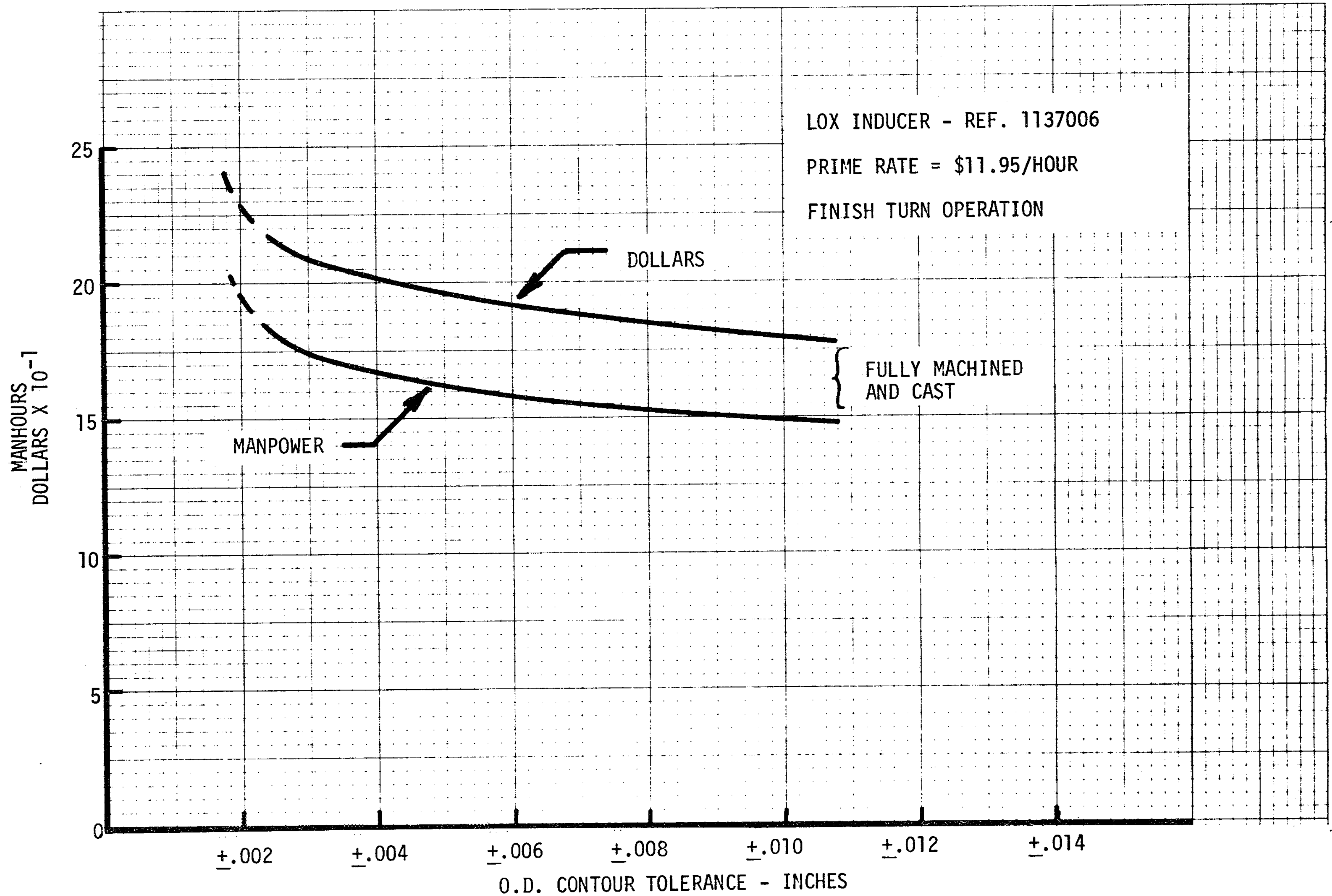


Figure 51. - Cost Effect of Vane Outside Diameter Tolerance, LOX Turbopump Item 20

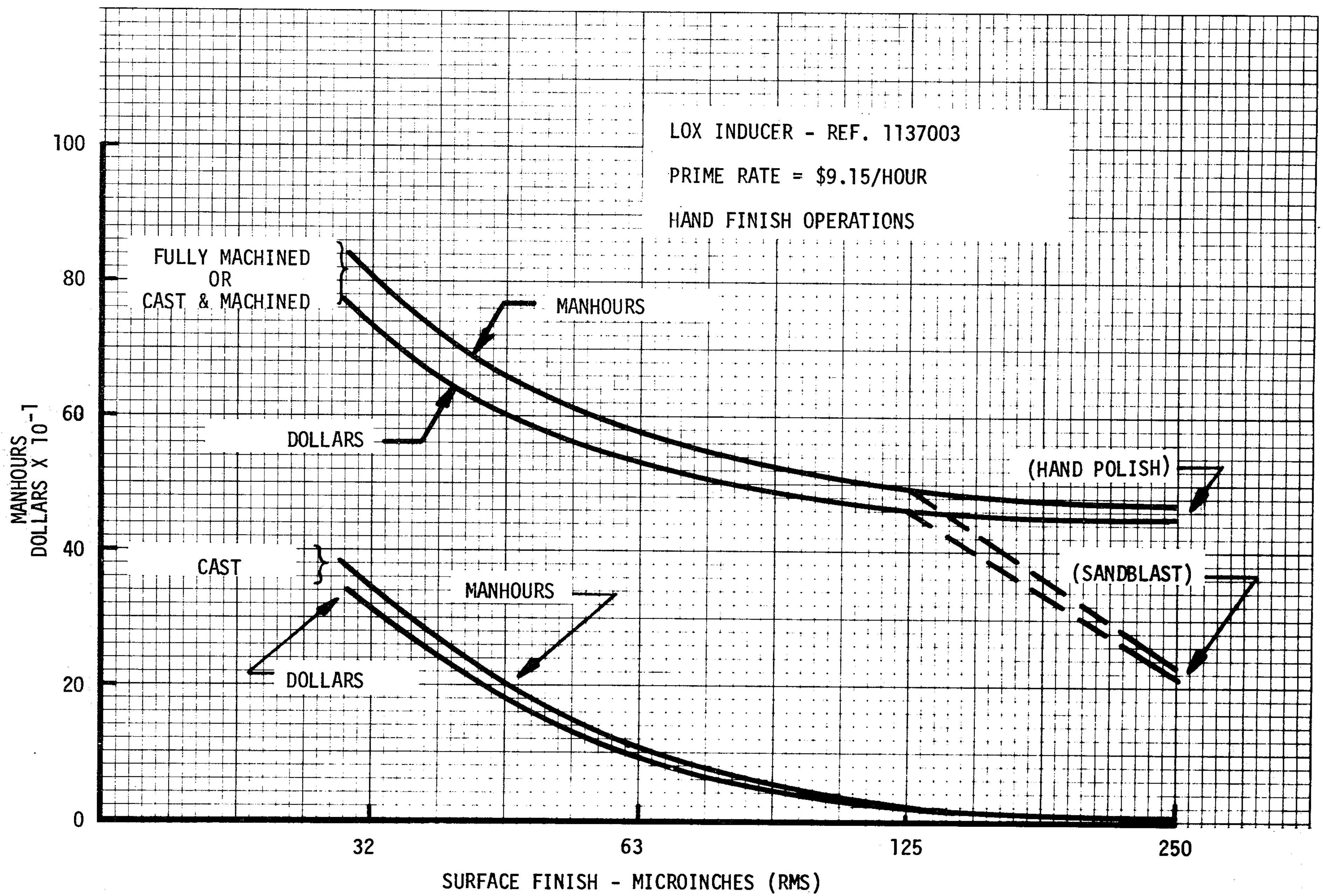


Figure 52. - Cost Effect of Surface Finish, LOX Turbopump Item 20

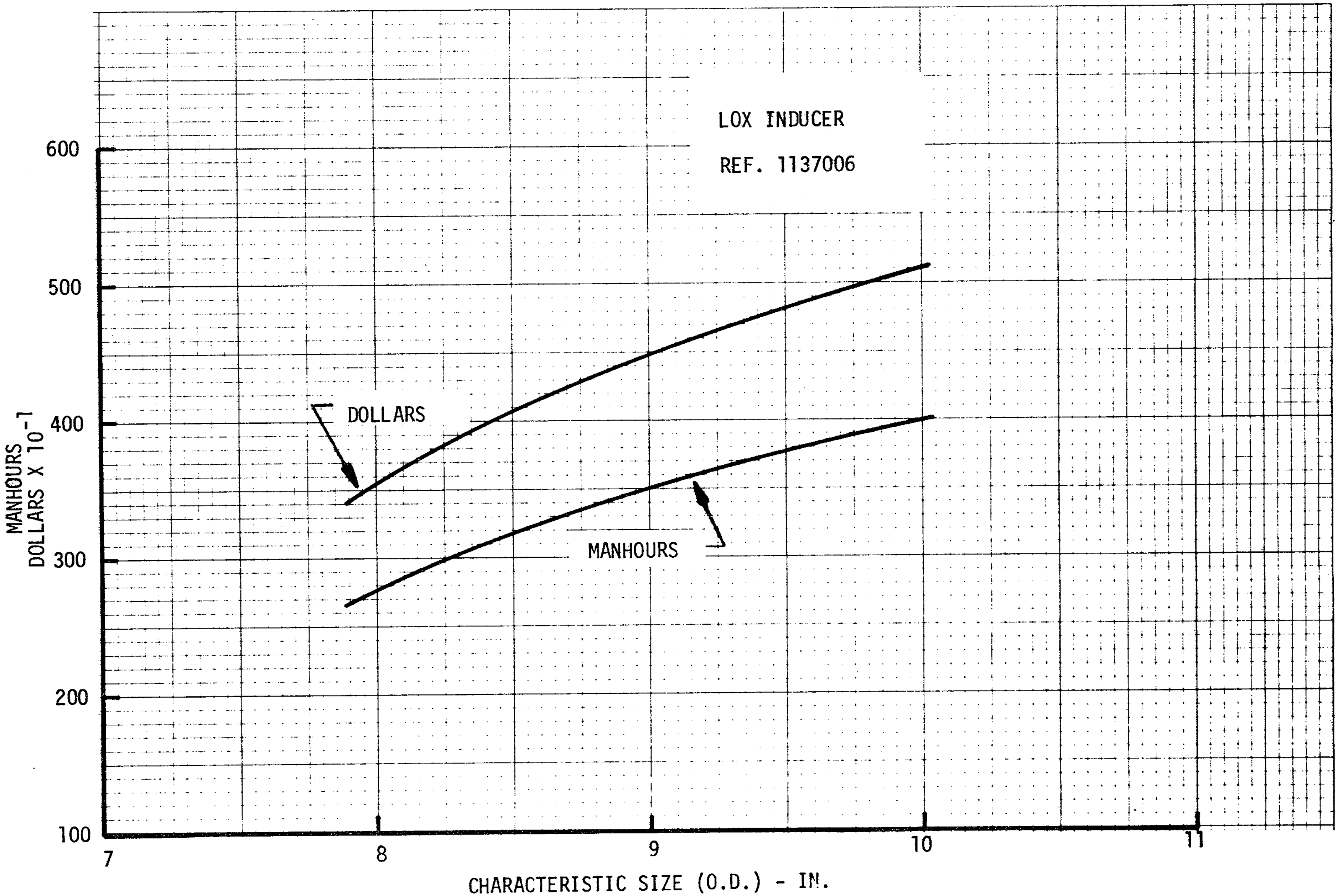


Figure 53. - Cost Effect of Size, LOX Turbopump Item 20

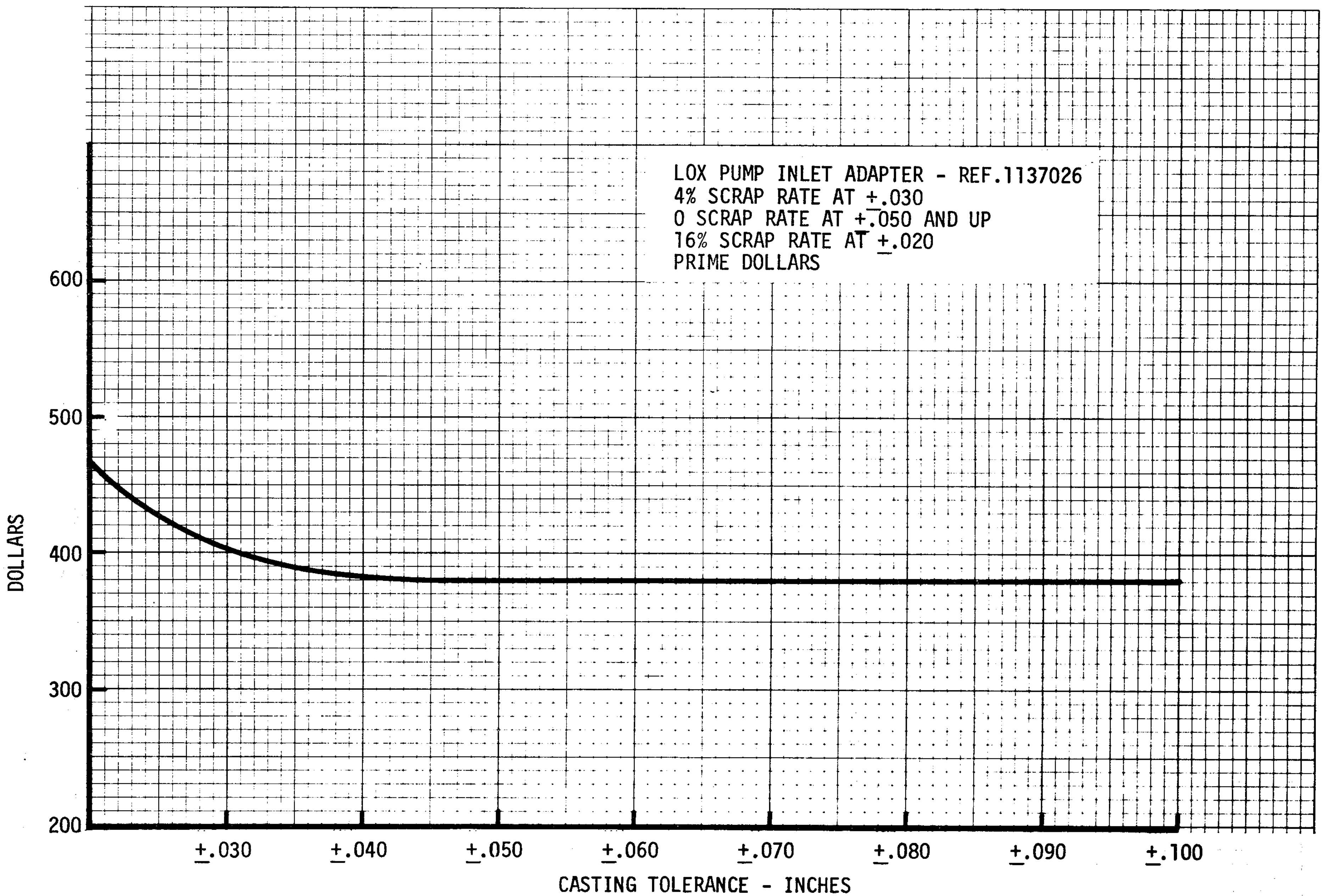


Figure 54. - Cost Effect of Casting Tolerance, LOX Turbopump Item 25

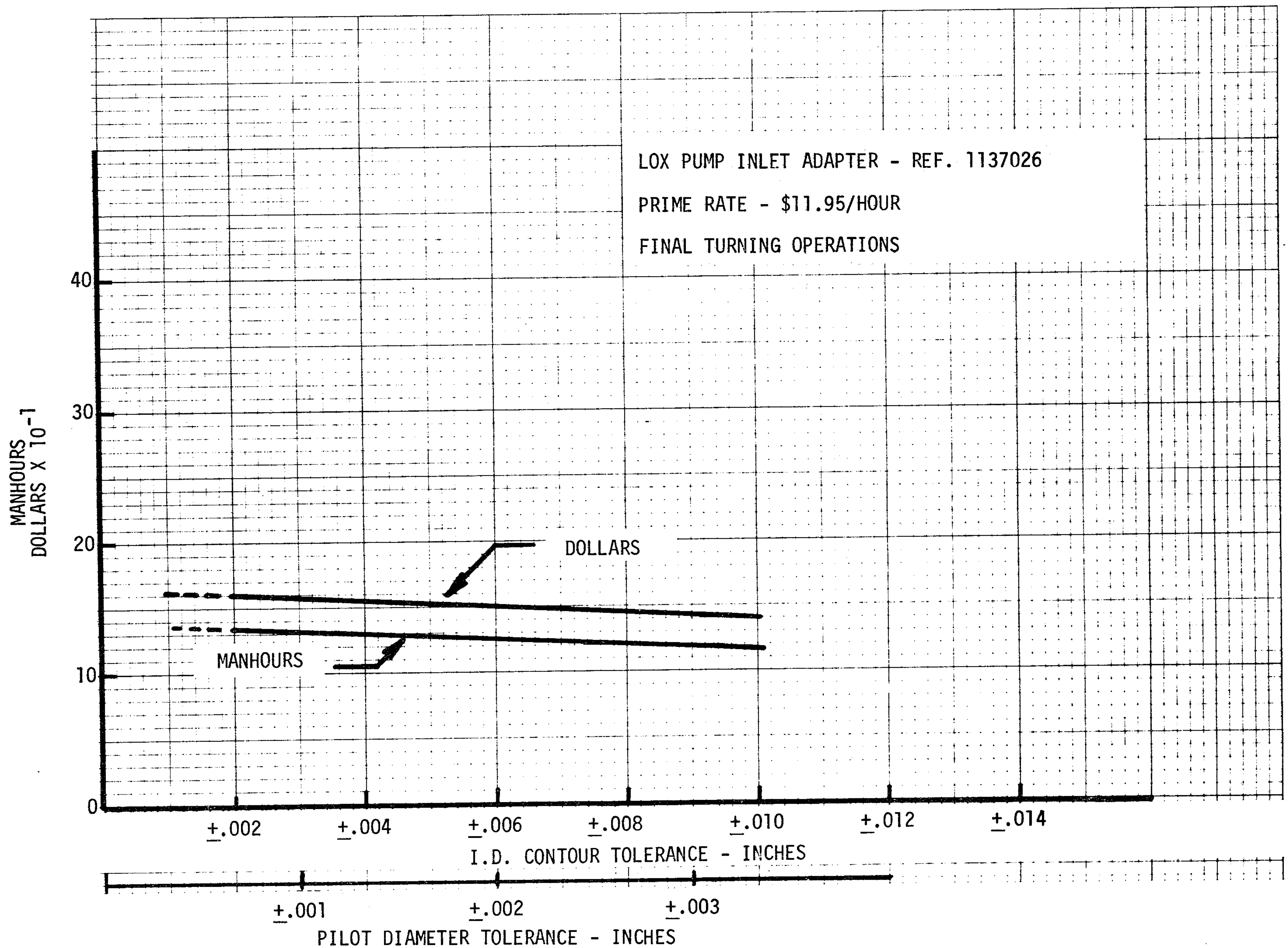


Figure 55. - Cost Effect of Pilot and Inside Diameter Contour Tolerance, LOX Turbopump Item 25

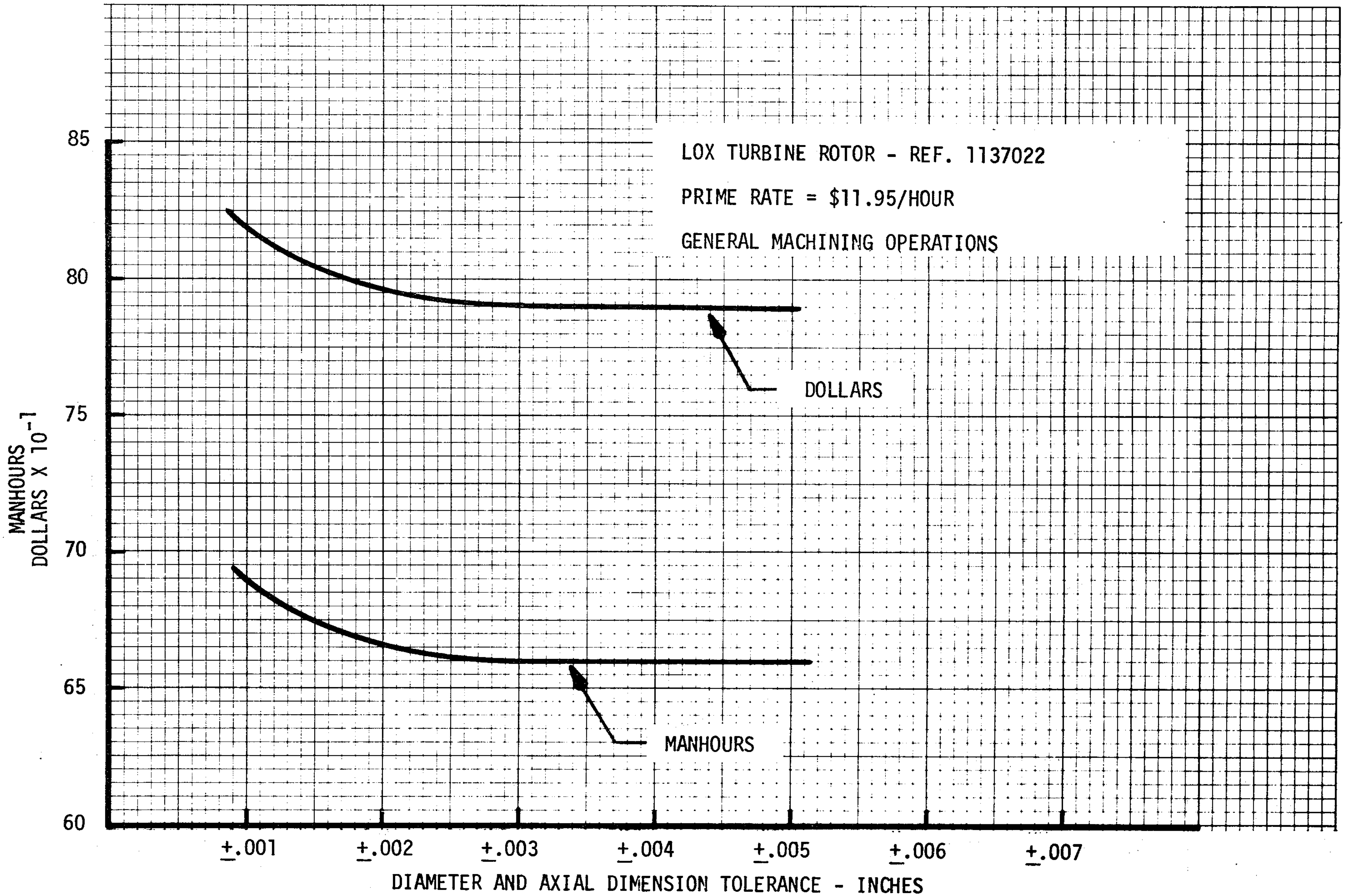


Figure 56. - Cost Effect of General Dimensional Tolerance, LOX Turbopump
Item 26

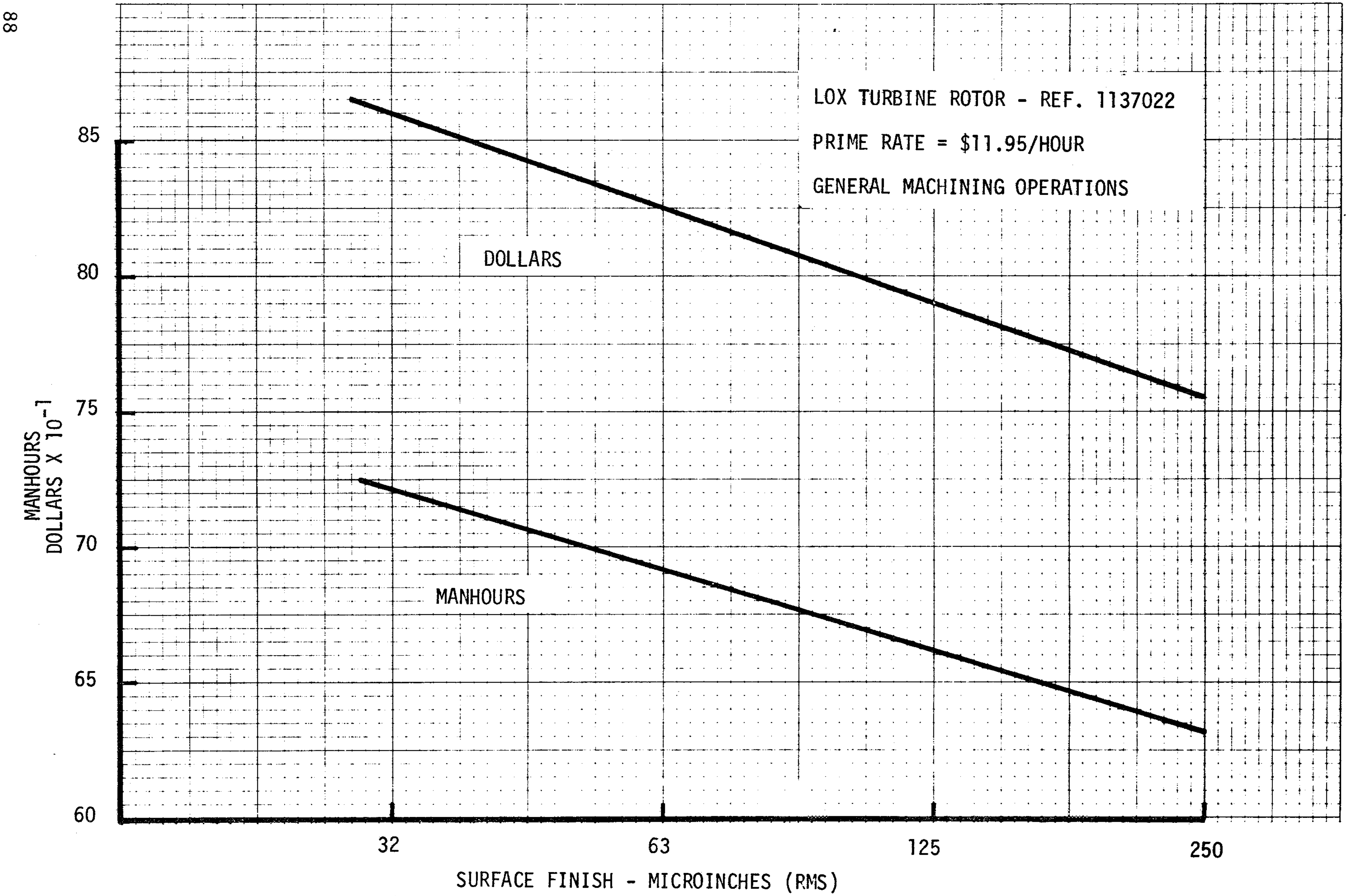


Figure 57. - Cost Effect of Surface Finish, LOX Turbopump Item 26

c Blade Profile Tolerance

A very strong 20% and 50% cost effect of rotor blade profile tolerance is shown on Figure No. 58 for two technological levels of obtaining the desired blade profile. Primary reasons for the reduction in both cast/machined and forged/machined versions is the reduced cutter replacement/sharpening time and the increased depth of cuts possible at the higher tolerances. A cast only version is not shown but would display no vane generating costs.

d Size Effect

Cost effects of general size for lumped forging and machining operations at the base case tolerance level are the same as those shown in Figure No. 17 for fuel turbine rotors.

15 LOX Turbopump Item 28 - LOX Turbine Manifold

a Critical Dimension Tolerance

Figure No. 59 gives the cost effect of critical dimensional tolerance such as the tolerances on pilot diameters and axial stacking planes. Machining time reduces rapidly by approximately 12% from ±0.002 to ±0.005 tolerance, but little effect is noted at higher tolerances. Inspection time does not vary significantly over the ±0.005 tolerance range.

b Vane Profile Tolerance

The effect of vane profile tolerance upon the cost of generating the vanes is shown on Figure No. 60 for two technological levels of performing the operation. The upper curves are for a fully-machined forged ring with integral machined vanes while the lower curves represent a model where integral vanes are first cast to some intermediate tolerance and then machined to final tolerance. A third (as-cast) version is implied but requires that vane profile tolerance be approximately ±0.010. A fixed casting prime cost of $900 or ring forging prime cost of $400 must be added to the appropriate curve value to compare alternative part production costs.

16 LOX Turbopump Assembly

a Stacking Dimension Tolerance

Assembly costs in terms of assembly labor manhours and total assembly net dollars versus critical axial stacking dimension tolerance are shown on Figure No. 61. Tolerances are assumed to be

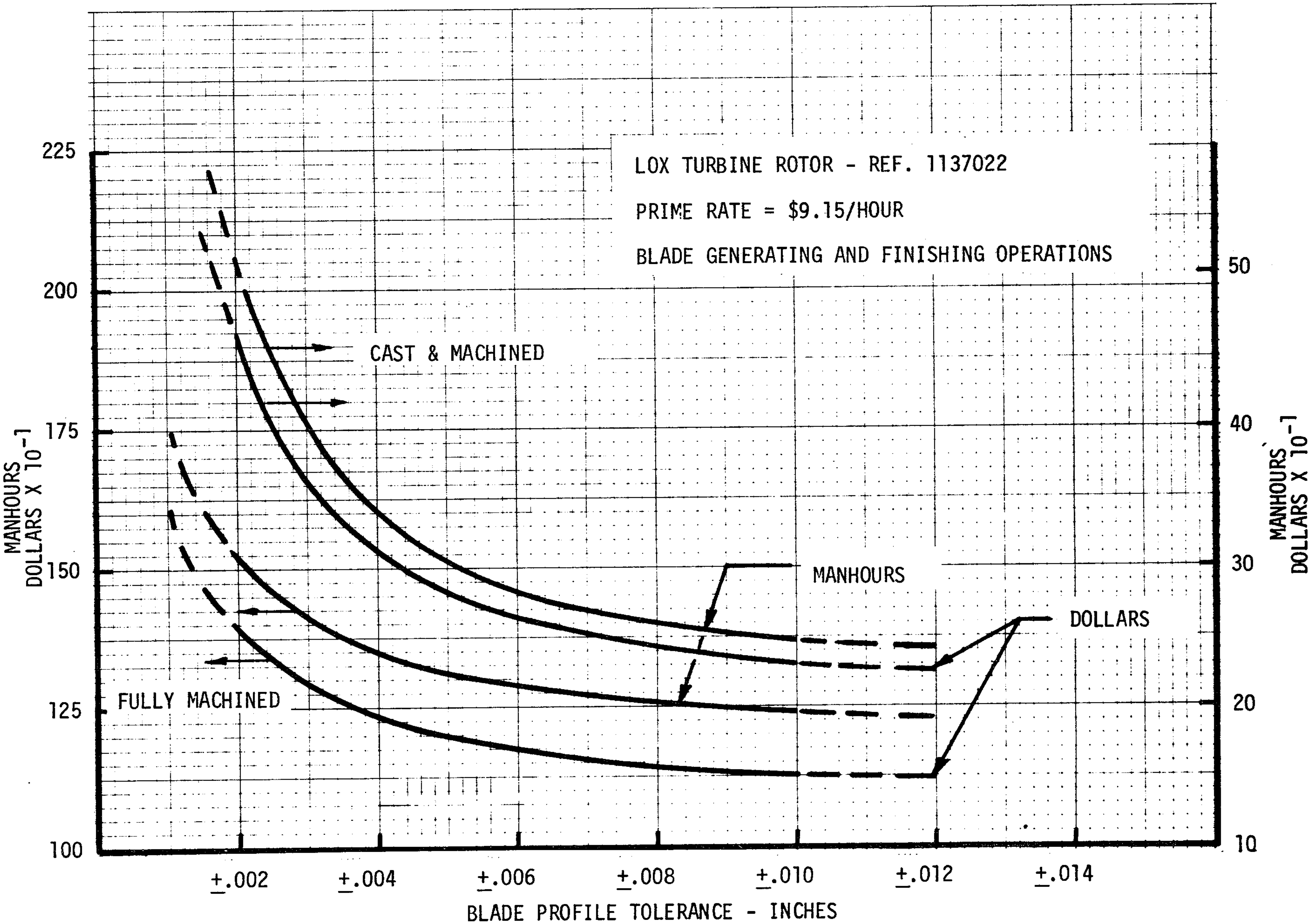


Figure 58. - Cost Effect of Blade Profile Tolerance, LOX Turbopump Item 26

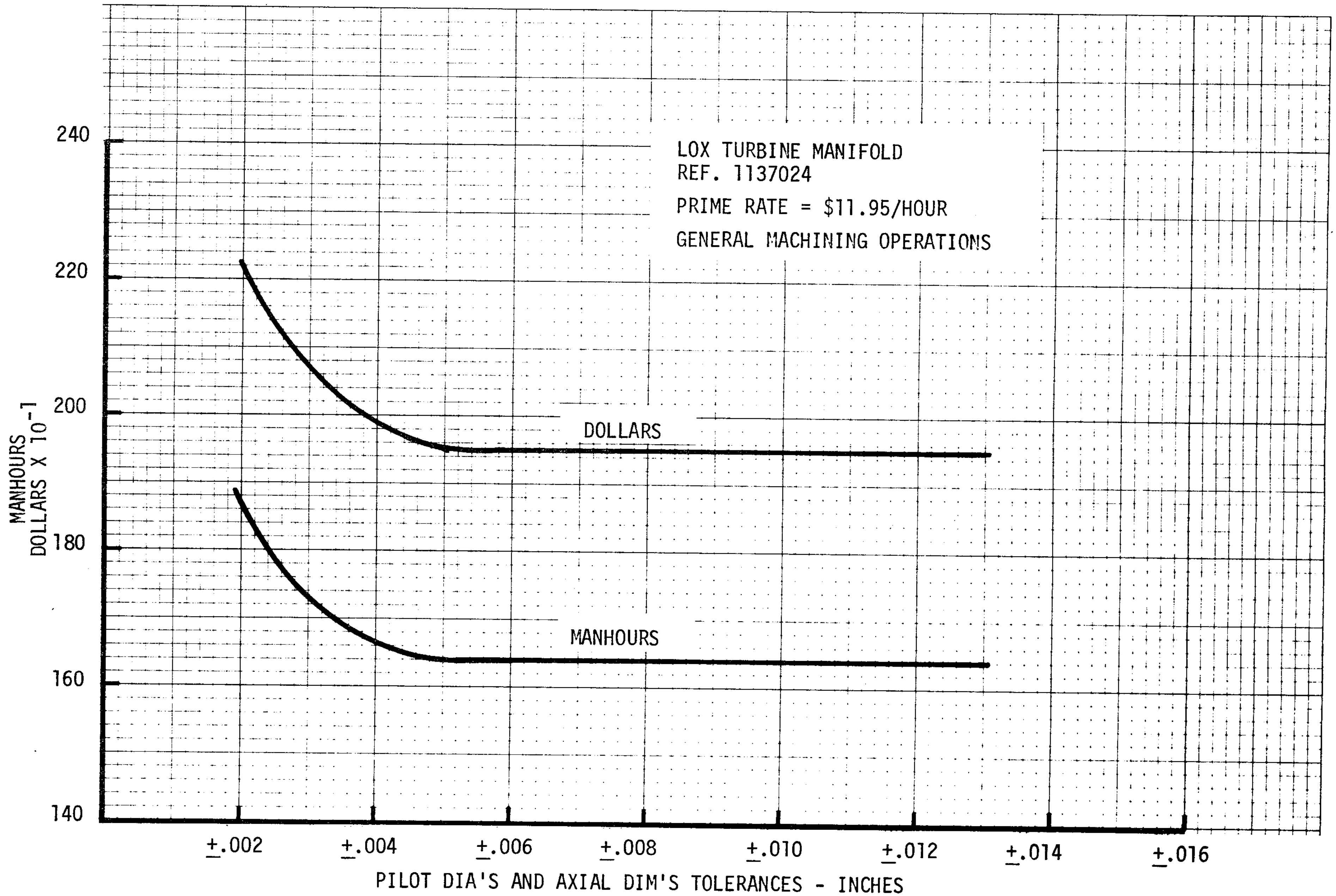


Figure 59. - Cost Effect of Critical Dimension Tolerance, LOX Turbopump Item 28

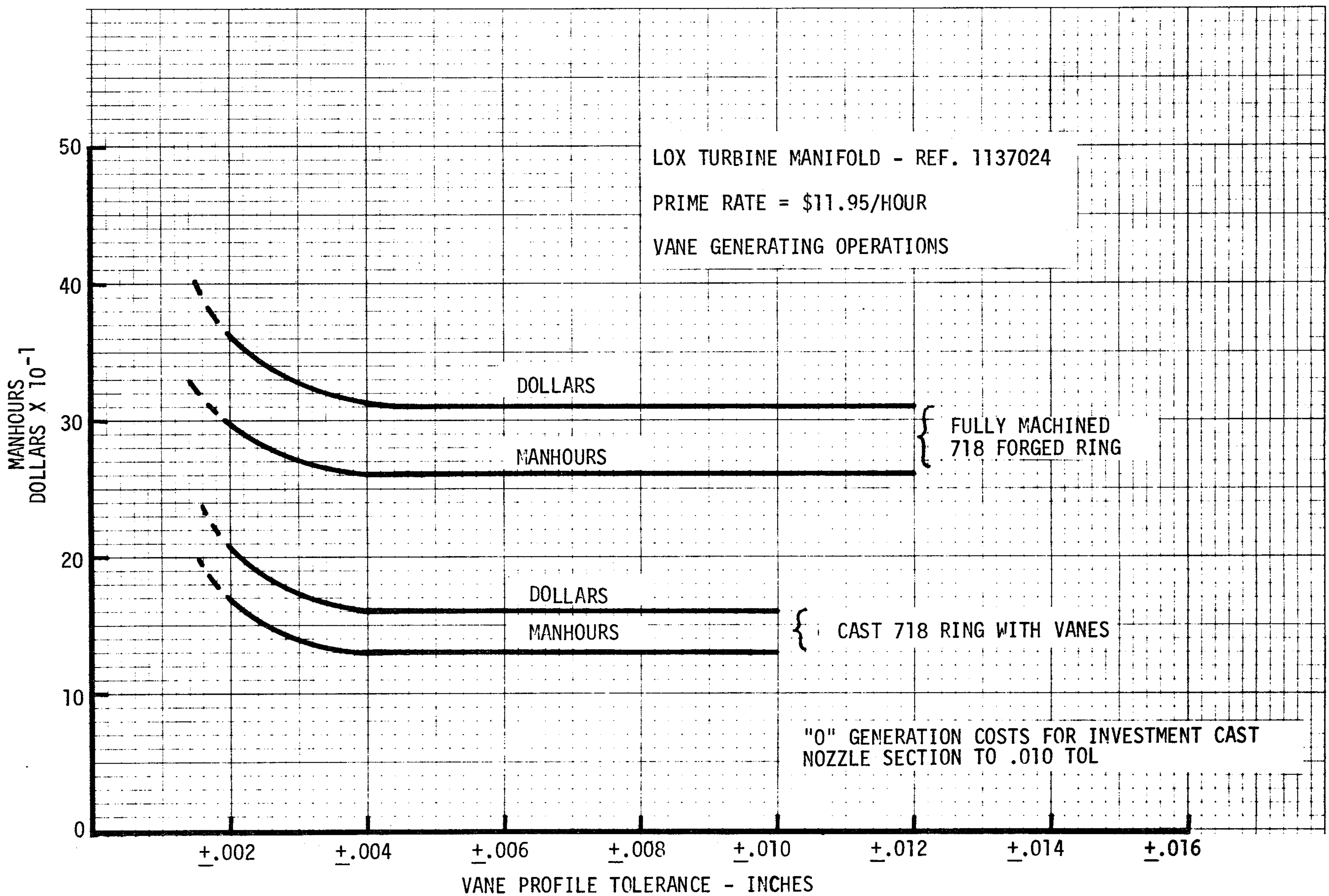


Figure 60. - Cost Effect of Vane Profile Tolerance, LOX Turbopump Item 28

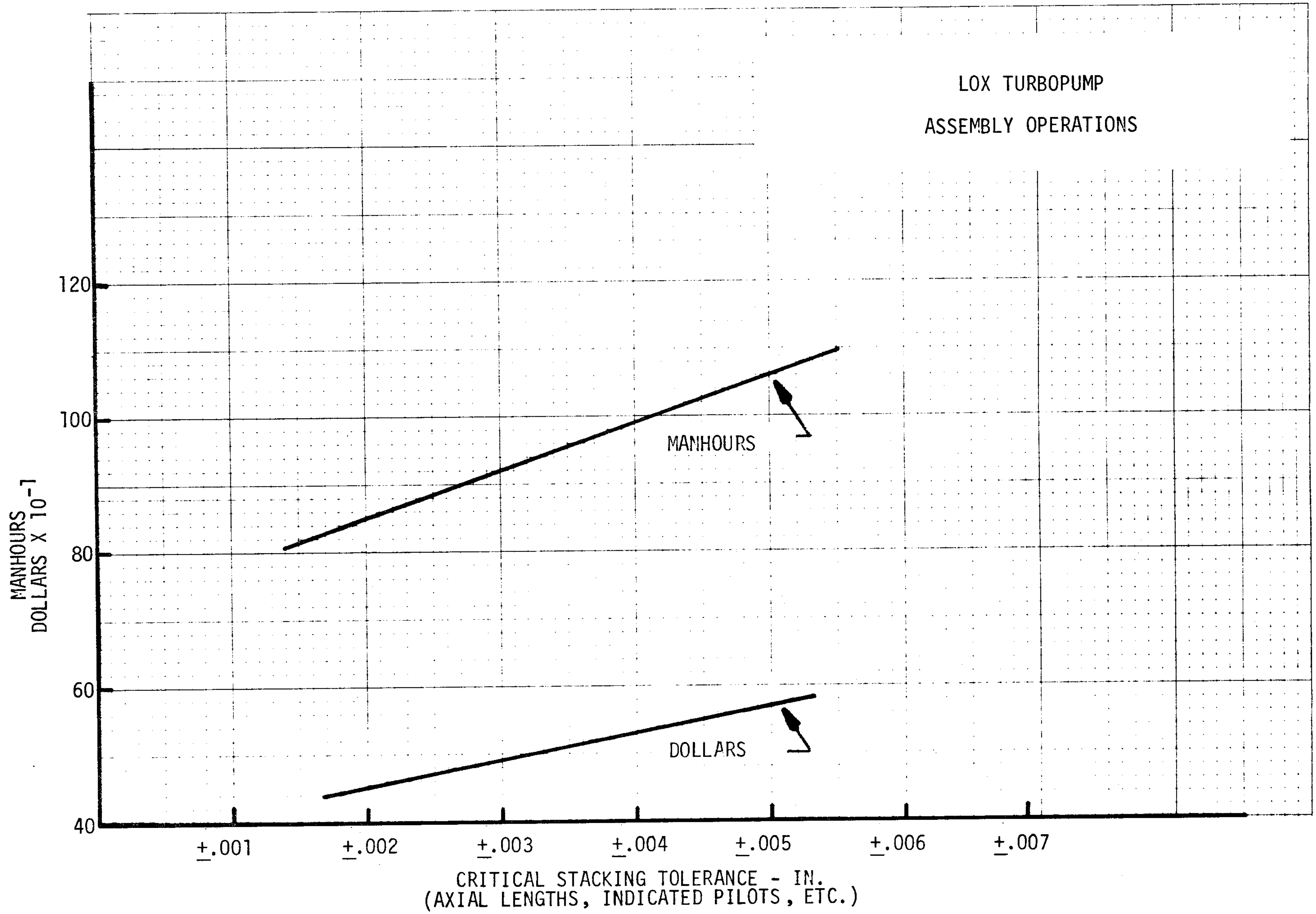


Figure 61. - Cost Effect of Stacking Dimension Tolerance, LOX Turbopump Assembly

distributed equally for the several parts affecting pump, seal, and turbine clearances. Assembly cost differences are totally attributable to the additional assembly operations required to custom-fit spacers/shims for larger tolerance parts.

<u>b</u> Size Effect

Figure No. 62 shows turbopump level size effect data for the total machine. These data were derived from the cost versus size data of Figures No. 45, No. 49 and No. 53, along with similar data for all major turbopumps subcomponents. Only net costs in dollars are shown as a function of required NPSH because no single hourly rate is applicable to all subcomponents.

(c) Development Phase Test Operations

Development test operations costs are not strongly dependent upon any other requirements than schedule and reliability for the class of machinery investigated in this study where the technology to execute a successful design clearly exists. As in the case of the design operations, the reliability levels required to assure that essentially no flight or mission failures can occur dictates that only the most rigorous development philosophy be used. It is not possible, within a reasonable schedular restraint of 10 years or less, to attain or demonstrate the required reliability without utilizing the full depth of every known turbopump development technique.

Accordingly, only one development test plan was formulated and costed as an implement for determining over-all program cost. Figure No. 3 is an outline of the development program thus formulated and forms the basis for the development test costs shown on Figure 63 and Table V. The following discussion outlines the philosophy and ground rules assumed in developing the costs.

To accomplish the development testing, it was assumed that existing Government or contractor-owned facilities would be used. Because all of these facilities currently exist at Aerojet, facilities cost estimates were limited to the following facility activation operations.

- Loading of propellants into storage and run tank systems.
- Dehydration and purging of facility system.
- Instrumentation of facility systems.
- Installation of flowmeters.
- Installation of flow spool.

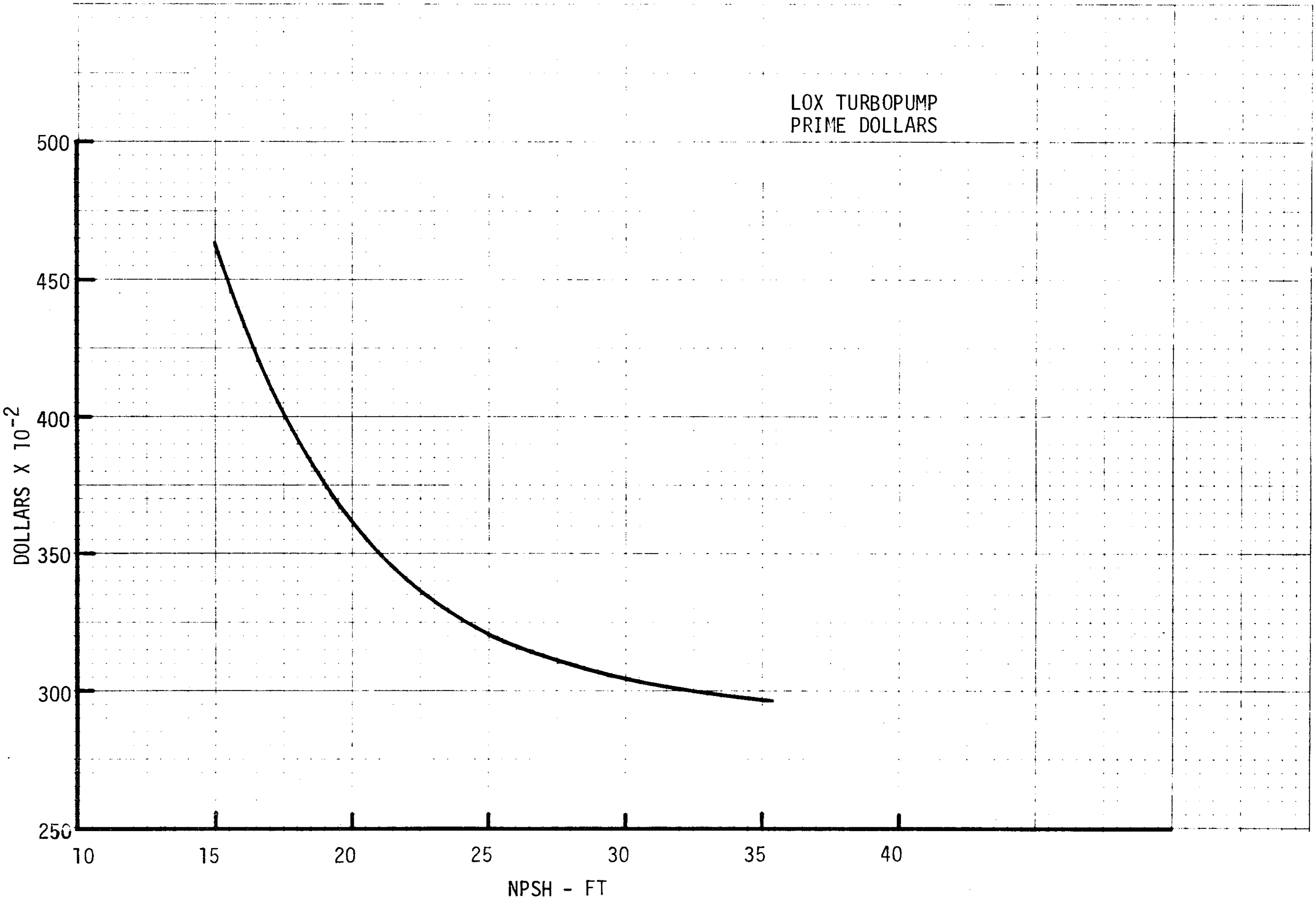


Figure 62. - Cost Effect of NPSH/Size, LOX Turbopump Assembly

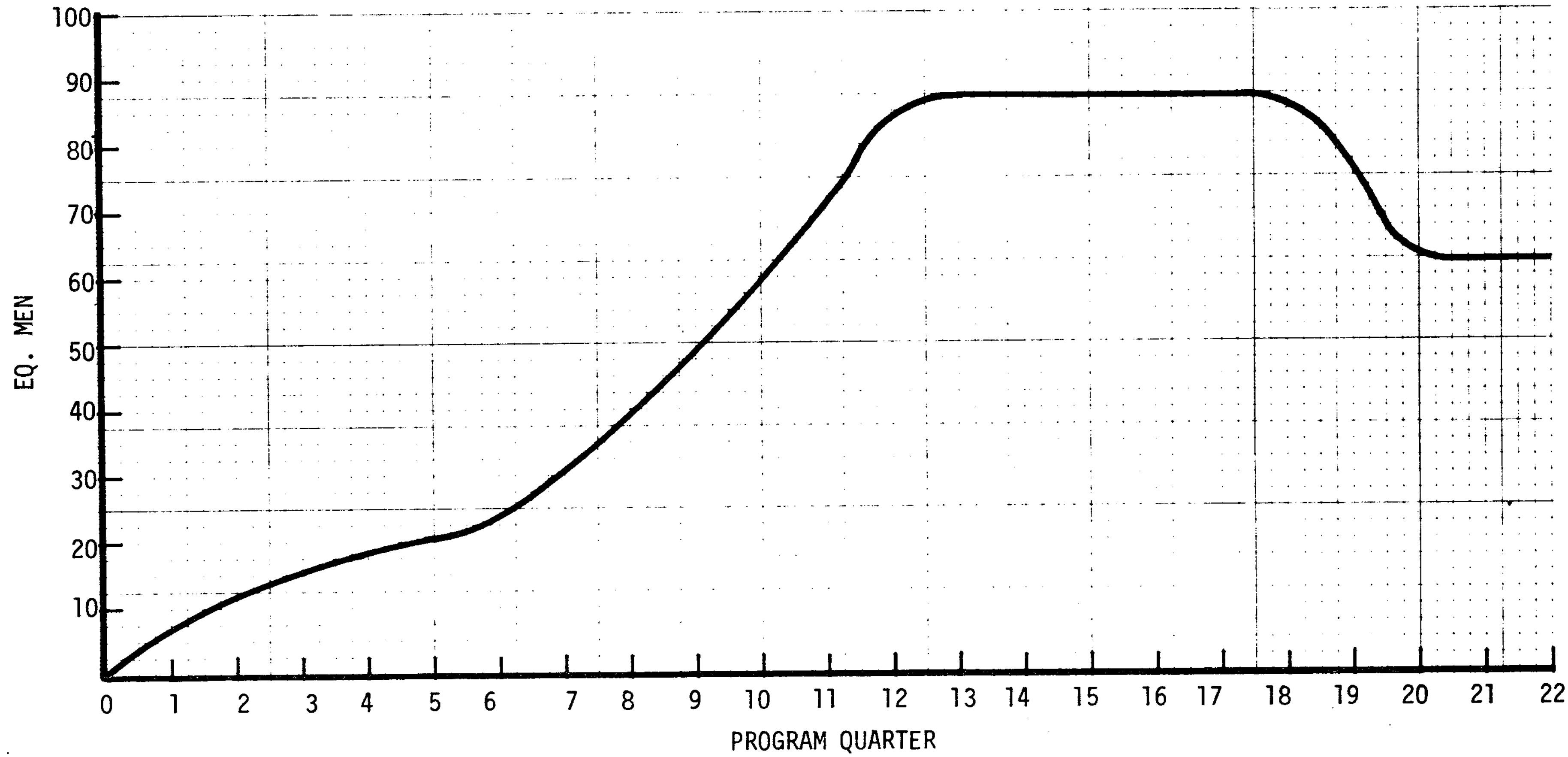


Figure 63. - R&D Program Manpower Chart

TABLE V. - DEVELOPMENT TEST COST SUMMARY

DEVELOPMENT TEST OPERATION	COST	
	MANQUARTERS	DOLLARS
1. Subcomponent test (part or feature level)		
a. Subcomponent proof tests		
(1) Rotor proof spin tests	11	132,000
(2) Housing pressure tests	11	132,000
b. Subcomponent Integrity Evaluation		
(1) Vibration Characteristics Definition (Blading)	6	72,000
(2) Housing Burst Pressure	8	96,000
(3) Rotor Burst Speed	8	96,000
(4) Bearing Life Tests	70	840,000
2. Component Tests (Sub-Assy Level)		
a. Pump Performance Evaluation	120	1,440,000
b. Power Transmission Performance Evaluation	0	0
c. Turbine Performance Evaluation	0	0
3. Turbopump Development Tests	835	9,900,000
4. Turbopump Acceptance Tests (Checkout for R&D Engines)	140	1,680,000
Total	1211	14,378,000

- Conducting facility leakage checks at ambient and cryogenic conditions.

- Functional sequencing of interacting systems.

- System cryogenic flow testing, both oxidizer and fuel.

- Installation of gas generator assembly and turbopump assembly.

- Gas generator assembly system functional and leakage checking at ambient and cryogenic conditions.

- Flow spool removal.

- Gas generator assembly checkout firing.

- Turbopump assembly mock-up installation for fit-up of gas generator assembly, suction line, discharge line, and exhaust line.

- Mock-up removal.

- Data review.

Development test manpower to support the program outlined on Figure No. 3 including the above facility activation report is shown by program quarter on Figure No. 63. The man loading displayed does not include the design engineering manpower required to plan the tests and interpret the results, because the engineering effort was included in the design costs shown on Tables III and IV and Figures No. 5 and No. 6.

Propellants were assumed to be Government-furnished and no consideration was given to the impact upon production capability or availability (see Production Phase Test Operations for quantities).

<u>1</u> Turbopump Test Capabilities

A two-position turbopump test complex would be required to meet the R&D test rate. Each of the two turbopump stands would be capable of accommodating a gas generator, a single liquid oxygen pump, or a single liquid hydrogen pump. Pump backpressure as well as transient and steady-state characteristics would be controlled by programming high response flow control valves. On-stand tankage for short duration start transient testing would be necessary for both the oxygen and fuel pumps during the development program. A set of high pressure run vessels would be required to supply propellant to the gas generators. The two test stands could be controlled and instrumented from a common control room.

Basic test stand and propellant vessel capability requirements would be as follows.

a Base Structure

The base concrete structure must be capable of withstanding the forces generated by the gas generator and pump as well as the loading of a stand tank and propellant flow transients.

b Superstructure

Superstructures must be capable of carrying the full transient load condition which is expected to occur during any test contemplated. This includes ramping of suction and discharge pressures to simulate acceleration characteristics in the propellants.

c On-Stand Turbopump Assembly Transient Vessels

LH_2 - One 5,000 gal, 100 psi vacuum jacketed

LO_2 - One 22,000 gal, 100 psi; insulated

d On-Stand Gas Generator Assembly Vessels

LH_2 - One 7,000 gal, 2,000 psi, vacuum jacketed

LO_2 - One 400 gal, 2,000 psi, non-insulated

e Off-Stand Run and Catch Vessels

LH_2 Run and Catch - Two 75,000 gal, 100 psi, vacuum jacketed, 10 in. outlet

LO_2 Catch - One 22,000 gal, 100 psi vacuum jacketed

f Propellant and Pressurant Storage

LH_2 - One 100,000 gal, 100 psi vacuum jacketed and one 13,000 gal, 100 psi for GH_2 conversion

LO_2 - One 28,000 gal, 100 psi vacuum jacketed

LN_2 - One 13,000 gal, 100 psi vacuum jacketed

The LH_2 and LO_2 catch vessels listed above also serve as storage vessels.

GN_2 Cascade - Two 1,300 ft^3, 5,000 psi vessels

GN_2 Cascade - Two 1,300 ft^3, 5,000 psi vessels

g Gas Conversion Systems

GN_2 - One 74,000 SCFH, 5,000 psi

GH_2 - Two 74,000 SCFH, 5,000 psi

h Instrumentation

The following minimum instrumentation capability should be provided and would be switched between the two stands from a common control room:

Input:	72	pressure measurements
	84	temperature measurements
	24	special wide band measurements
	84	miscellaneous traces and flow
Recording:	138	digital channels
	40	visual displays
	32	wide band channels
	5	oscillographs

Servo Control Systems for Valves: Tank pressurization, liquid flow control, and pump backpressure control.

i Test Duration

With the above capability a 300 sec run duration is available.

$\underline{2}$ Turbopump Subcomponent Test Facilities

Turbopump subcomponent development testing would require the following specialized facilities as well as universal vibration, spin, and thermal shock test facilities.

$\underline{a}$ LH_2 Bearings and Seals Test Bays

With the criteria established for a maximum test rate of 12 tests per week, it is necessary that two test positions be provided. Each test position would be supplied with all necessary working fluids from a common source (i.e., LH_2 run tanks). However, each position should be equipped with an electrically-driven bearing tester which is capable of variable speed control from 0 to 40,000 rpm.

Because the bearing tests are of long duration, one centrally located, vacuum jacketed run tank of 8,650 gal capacity with a preferred design pressure of 1,800 psi would be needed to provide high pressure liquid hydrogen to each test bay through 2.0-in.-vacuum insulated piping.

$\underline{b}$ LO_2 Bearings and Seals Test Bays

Two positions similar to those for the above LH_2 testing would be required for LO_2 to accommodate the same rate.

One centrally located, single-walled vessel of 8,650 gal and 1,800 psi design pressure would be required.

$\underline{c}$ LH_2 Storage

Two 14,000 gal, 100 psi vacuum-jacketed storage vessels should be provided with one truck/trailer unloading station in support. Two vessels are desirable to provide system flexibility during concurrent LH_2 off-loading and transfer and LH_2 converter operation.

$\underline{d}$ LO_2 Storage

Storage similar to that described for the LH_2 would be required for LO_2.

$\underline{e}$ LN_2 Storage

One 13,000 gal, 100 psi vacuum-jacketed storage vessel is needed to supply the LN_2 converters. This vessel should be supported by a single trailer unloading station.

$\underline{f}$ LH_2 Converter

One 74,000 SCFH or two, 36,000 SCFH each, 5,000 psi converters are needed.

$\underline{g}$ LN_2 Converter

Two 74,000 SCFH, 5,000 psi converters are required. Both LN_2 and LH_2 high pressure pumps should be electric-motor-driven. All vaporizers should be of a steam or hot water heat exchanger type. Liquid supply for each system should be provided from the test facility LN_2 or LH_2 storage tank. No separate tank is needed for the converter supply.

$\underline{h}$ Support Facilities

In addition to the major facilities described above, the following support facilities are needed at a readily accessible location to the turbopump assembly and component test complexes.

- Instrumentation Repair and Calibration Shop
- Flowmeter Calibration Facility
- Valve Repair Shop
- Mechanical Machine Shop
- Clean Room Facilities
- Vibration Facilities
- Data Processing Equipment
- Office and Engineering Buildings

(d) Production Phase Design Operations

Design operations during the production phase of a high reliability rocket engine turbopump must be limited to those required for performance-oriented modifications (to satisfy changing engine requirements) and to mechanical feature modifications (to satisfy life/reliability requirements under unanticipated flight environments). Any redesign for ease of production would invalidate the results of the development/qualification program. Therefore, production phase design operations are not a definable function of design requirements and cost studies were limited to definition of the design manpower required to make the types of modifications indicated. The manpower requirements thus defined are summarized on Table VI and are invariant with design requirements.

TABLE VI

PRODUCTION PHASE - DESIGN OPERATIONS COST SUMMARY

Activity/Discipline	Manpower (Manyears)
Performance Modifications	
Pump Hydraulics	18
Turbine Aerodynamics	18
Mechanical Modifications	
Design Engineering	9
Structural Analysis	12
Drafting	18
Total	75

(e) Production Phase Fabrication Operations

In keeping with the philosophy that the production turbopumps must be identical to those qualified, production phase fabrication operations are related to design requirements in exactly the same manner as previously discussed for development fabrication operations.

The cost estimates were all prepared under the assumption of high volume production and the tooling costs shown in Appendices H and I reflect that assumption. Production lot sizes larger than 40 to 50 were not specifically investigated but discussions with contributing suppliers indicate no significant change in cost would occur within the range from 50 to 100 units. Some significant additional reduction might occur in the range from 100 to 1000 units, but it did not appear that the reference application program would approach this number at the time the estimates were prepared.

(f) Production Phase Test Operations

Production Phase Test Operations can be divided into the following five subcategories and operations:

1 Subcomponent Level Tests
 - a Rotor Proof Spin Tests
 - b Housing Proof Pressure Tests

2 Component Level Tests
 - a Pump Calibration
 - b Turbine Calibration

3 Turbopump Level Tests
 - a Acceptance Tests
 - b Post-Test Checkout and Inspections

4 Engine Level Tests
 - a Engine Acceptance Tests
 - b Post-Test Checkout and Inspections

5 Stage Level Tests
 - a Flight Readiness Tests
 - b Post-Test Checkout and Inspections

The MLLV Program ground rule requirements of engine acceptance test and stage static test firing (Ref. 1) eliminated the last two subcategories from consideration. Therefore, the optimum method for performing the production phase test operations is that combination of the first three subcategories which will sustain the performance and reliability requirements at the lowest cost.

Past programs have generally utilized elements of all three levels of tests to assure that the requirements were met. Consequently, little data exists to support the elimination of entire subcategories. However, the bulk of the test cost is incurred during the turbopump level acceptance tests and checkout. Therefore, programs including as well as omitting these tests were studied.

The program plan includes the turbopump acceptance plans and was prepared for three production rates. Figure No. 3 shows the minimum production rate of 60 units per year (Ref. 1). Alternative programs at double and quadruple that rate were postulated. The three rates result in production test program lengths of 18, 9 and 4-1/2 years, respectively.

The previously described development test facility capability would be adequate for the base 60 unit per year production rate but to effectively double the test rate, a second complex of two test stands would be required. These stands would be physically identical to the first complex stands. If possible, the second complex should be located near the first one to permit the common utilization of the off-stand run vessels, catch vessels, and storage capabilities by both complexes. However, no such facility exists and a utilization of existing contractor or Government-owned facilities would require a completely separate facility at some other location. The quadrupled test rate would again double the number of test positions required and result in additional test planning as well as follow-up manpower because of the separate geographical locations required to utilize existing facilities. The manpower estimates for the high production rate (240 unit/year) include these additional test planning and follow-up personnel. Production test manpower is shown by program year on Figures No. 64, No. 65 and No. 66 for 60, 120, and 240 unit/year test rates, respectively. Total costs for each alternative (excluding propellants) are shown on Table VII.

TABLE VII. - PRODUCTION PHASE - TEST OPERATIONS COST SUMMARY

Production Rate	Test Operations Costs
60 Units/Year	$44,200,000
120 Units/Year	$45,200,000
240 Units/Year	$46,200,000

Propellants were assumed to be Government-furnished and no consideration was given to the impact upon propellant production, capability or availability for the various program alternatives. However, propellant usage for the three alternatives is shown on Table VIII.

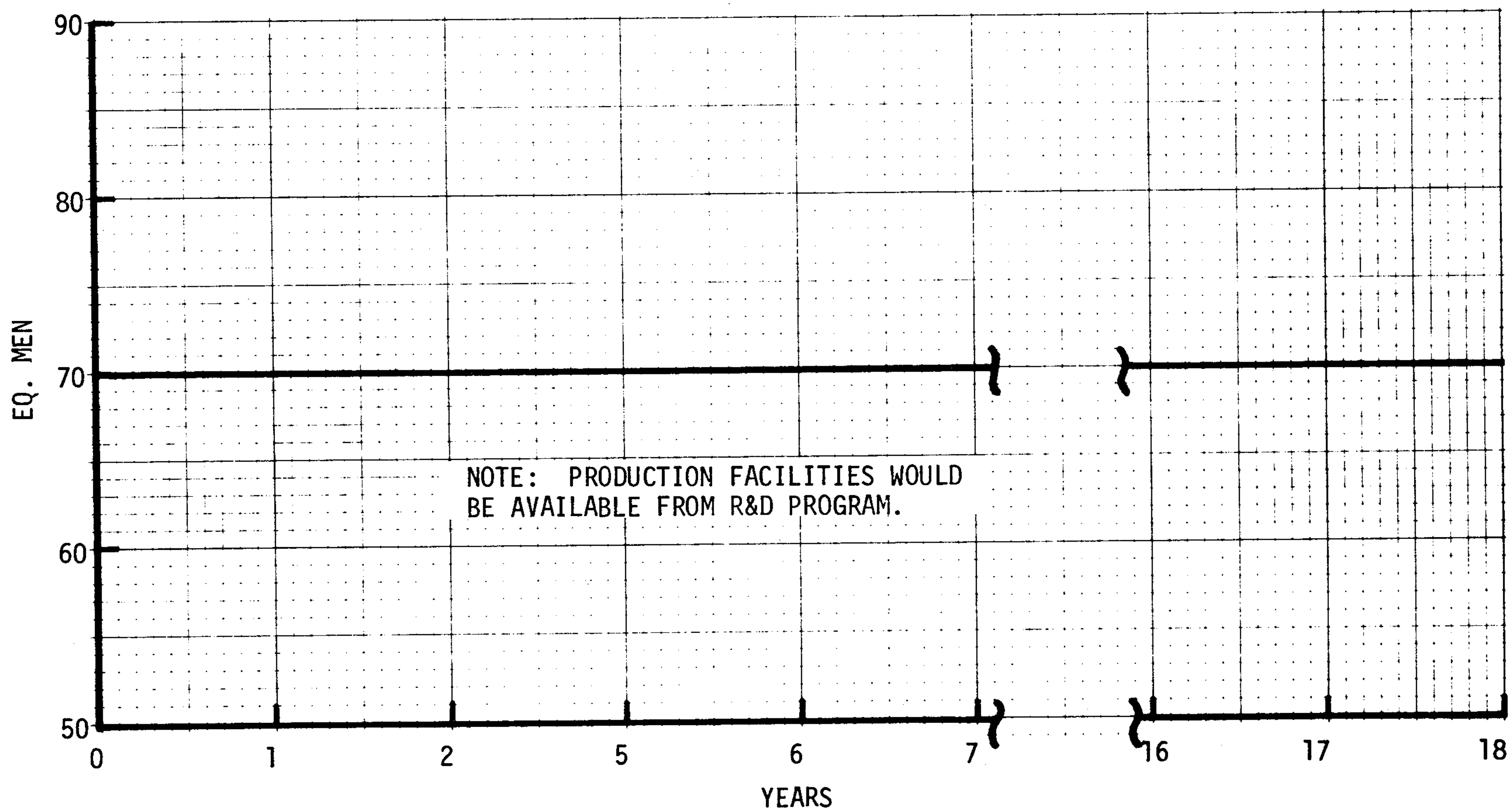


Figure 64. - Manpower Chart, 60 Units/Year for 18 Years

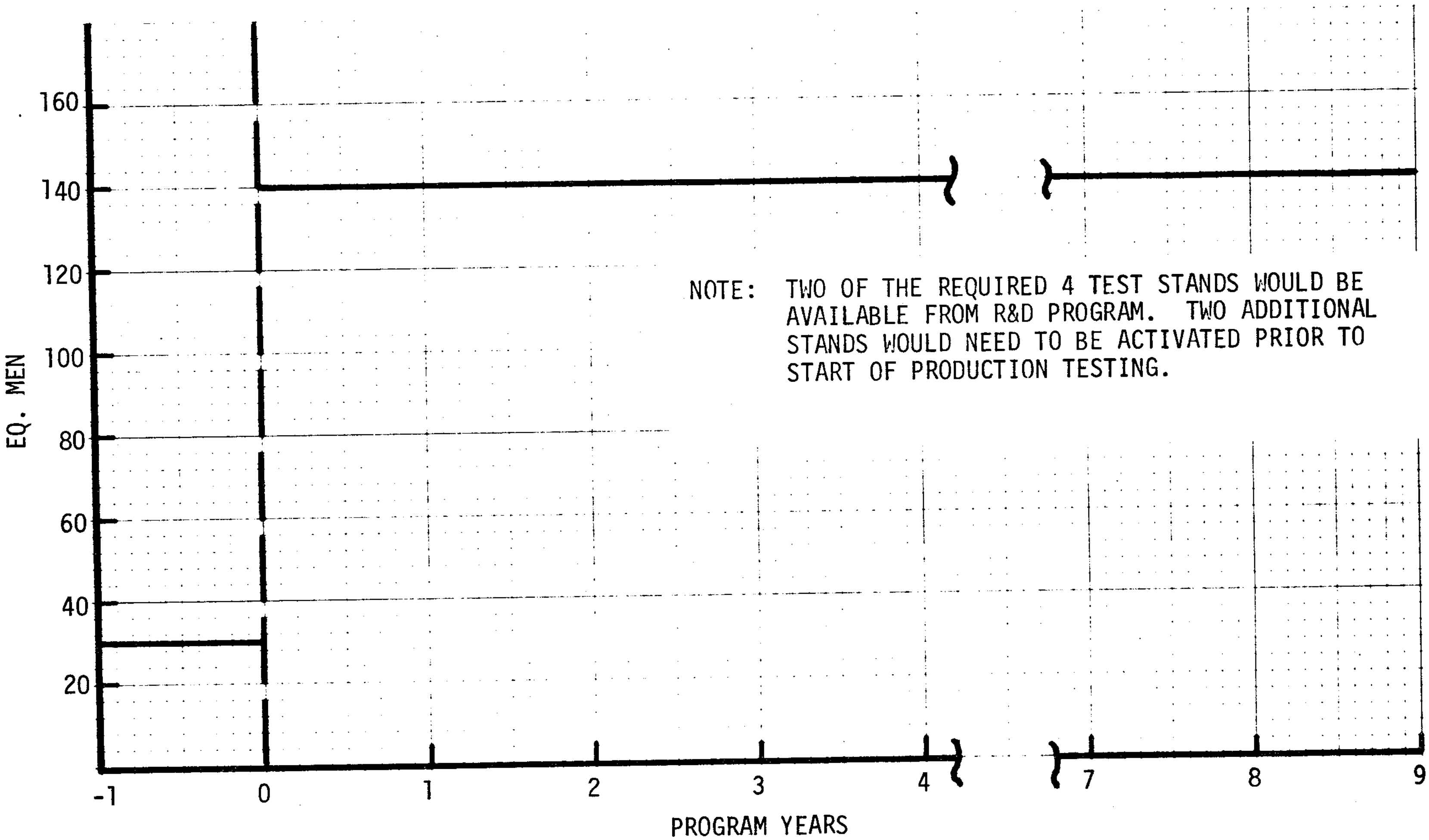


Figure 65. - Manpower Chart, 120 Units/Year for Nine Years

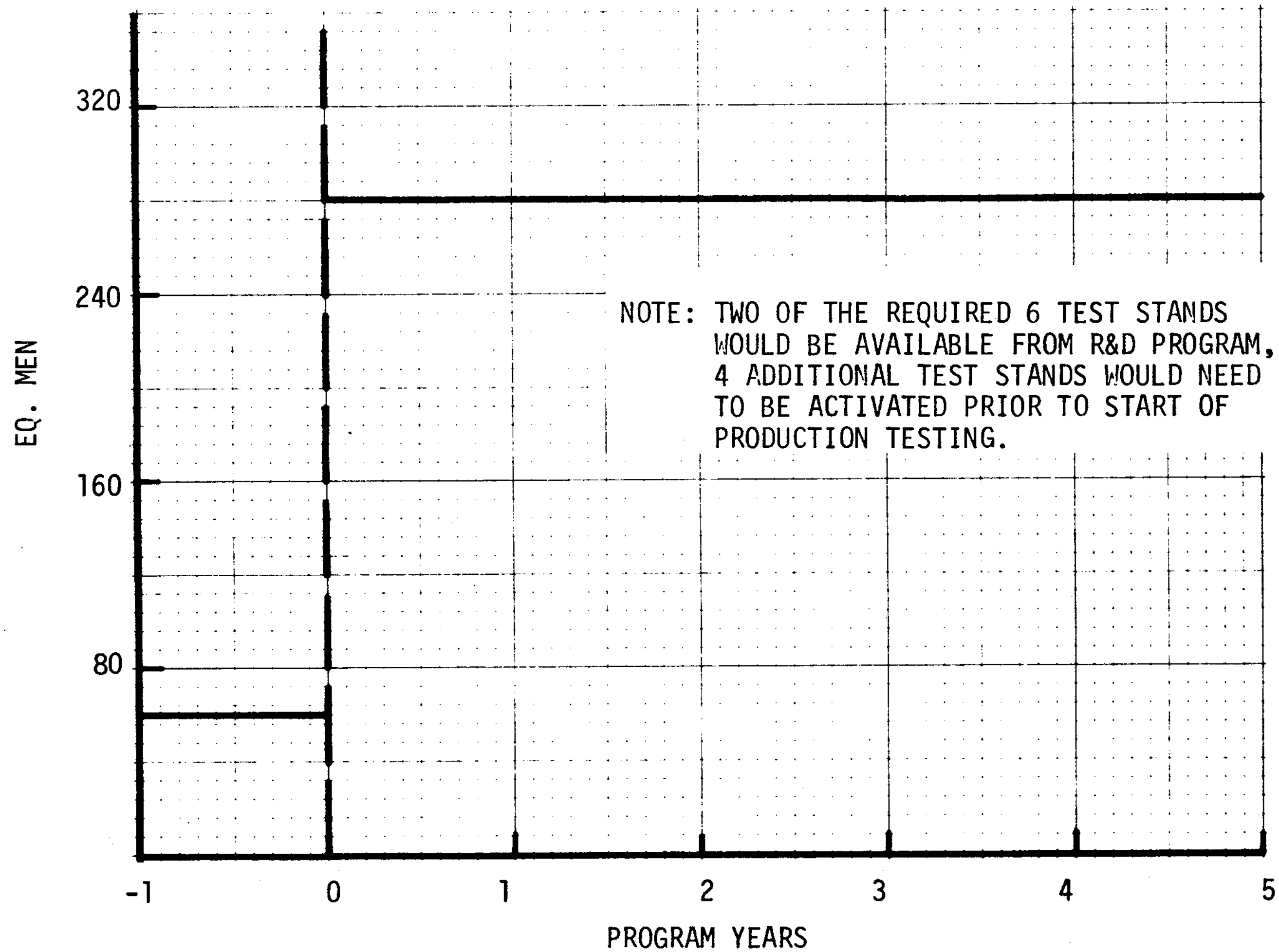


Figure 66. - Manpower Chart, 240 Units/Year for Four and One-Half Years

TABLE VIII. - PROPELLANT REQUIREMENTS

Production	LH_2 lb	LO_2 Tons	LN_2 Tons	GHe - MSCF
ALTERNATIVE I (60 UNITS/YEAR)				
1	2,552,000	5,500	7,600	577
2	2,552,000	5,500	7,600	577
3	2,552,000	5,500	7,600	577
4	2,552,000	5,500	7,600	577
5	2,552,000	5,500	7,600	577
6	2,552,000	5,500	7,600	577
7	2,552,000	5,500	7,600	577
8	2,552,000	5,500	7,600	577
9	2,552,000	5,500	7,600	577
10	2,552,000	5,500	7,600	577
11	2,552,000	5,500	7,600	577
12	2,552,000	5,500	7,600	577
13	2,552,000	5,500	7,600	577
14	2,552,000	5,500	7,600	577
15	2,552,000	5,500	7,600	577
16	2,552,000	5,500	7,600	577
17	2,552,000	5,500	7,600	577
18	2,552,000	5,500	7,600	577
	45,963,000	99,000	136,800	10,386
ALTERNATIVE II (120 UNITS/YEAR)				
1	5,104,000	11,000	15,200	1,154
2	5,104,000	11,000	15,200	1,154
3	5,104,000	11,000	15,200	1,154
4	5,104,000	11,000	15,200	1,154
5	5,104,000	11,000	15,200	1,154
6	5,104,000	11,000	15,200	1,154
7	5,104,000	11,000	15,200	1,154
8	5,104,000	11,000	15,200	1,154
9	5,104,000	11,000	15,200	1,154
	45,936,000	99,000	136,800	10,386
ALTERNATIVE III (240 UNITS/YEAR)				
1	10,208,000	22,000	30,400	2,308
2	10,208,000	22,000	30,400	2,308
3	10,208,000	22,000	30,400	2,308
4	10,208,000	22,000	30,400	2,308
5	5,104,000	11,000	15,200	1,154
	45,936,000	99,000	136,800	10,386

The program plan wherein the formal turbopump acceptance tests are eliminated actually defers the mechanical and performance checkout of the turbomachinery until the engine level acceptance tests. Titan and Gemini engine production test program results offer some evidence that such an approach is feasible. The negligibly low assembly error incidence achieved in those programs virtually eliminated the necessity to verify the turbopump mechanical integrity by a hot firing test of the turbopump alone.

However, the hydraulic and aerodynamic performance data obtained during a turbopump acceptance test serves as prime input for the initial engine trim or calibration. Attempts to trim the engine based upon nominal turbopump performance levels often resulted in unacceptable thrust or mixture ratio conditions. The variations in turbopump hydraulic and aerodynamic performance which must be accounted for in the engine trim are related to the subcomponent design requirements previously discussed. However, this dependency of acceptance test and engine trim requirements upon subcomponent design requirements was not recognized early enough in the study. Only minimal useful data was obtained at the more stringent requirements that are necessary to reduce component performance scatter to a level which would allow initial engine trim to be made accurately without first calibrating (acceptance test firing) the turbopump. The subcomponent cost data generated can be extrapolated to more stringent requirement levels but the subsequently discussed performance analysis was not extended over a sufficient range to allow definition of requirements levels where calibration would not be needed. For the purposes of developing the study objective of cost optimization methodology, it was assumed that the most stringent requirement/performance levels studied corresponded to the level where calibration can be eliminated. This approach merely serves to illustrate the technique which would be used in an actual production program.

The cost of the production phase test operations for the program alternative described above would be reduced from the base case program by the entire turbopump acceptance test manpower costs as well as the propellant costs for the 60 unit-per-year production rate. The higher production rate alternatives would result in those same savings plus the additional facility activation cost savings.

(g) Production Phase Field Maintenance Operations

The Field Maintenance Operations performed on turbopumps normally are limited to periodic seal checks, periodic rotor torque checks, interface static seal replacement, and turbopump removal as well as replacement in the engine. These operations are performed to assess and provide any necessary remedies for the mechanical integrity or the performance (in terms of lost propellant) of the system. In the subject study, no way was found by which the cost of the mechanical integrity (torque) checks or resulting replacement operations could be traded with design requirement variations. However, the seal checking costs can be weighed against leakage requirements variations at two technological levels; all seals can be checked or those which are actually controlled leakage devices (i.e., labyrinths) can be excluded from the check. Seals are subject to handling/shipping damage while labyrinths are not. There is an obvious cost difference for field servicing the two types of machines. Titan/Gemini records show that 93 manhours-per-seal-per-check were expended, upon apportioned historical field service costs, and only two hours-per-seal were required, based upon apportioned historical post-fire inspection costs at the engine contractor's facility. The large discrepancy between the two can be partially attributed to the increased complexity of performing the check in the engine and stage, but the major difference appears to result from the need to maintain the checking capability during periods of inactivity.

(2) Design Requirements versus Component Performance

The base case component arrangement of series flow turbines and the turbopump configurations of single-stage centrifugal pumps, two-stage axial flow turbine, and single-stage axial flow LOX turbine strongly influence the relative worth of fuel turbopump versus LOX turbopump subcomponent performance in terms of engine specific impulse degradation through their effect upon gas generator or turbine flow rate. Ideally, the minimum turbine flow rate would occur when fuel and LOX turbopump component performance are balanced in a way that the required fuel and LOX turbine flow rates are exactly equal at the optimum turbine pressure ratio division. In practice, component performance variations from the nominal require that one turbopump performance be biased such that the turbine pressure ratio split can be varied to adjust the input power balance. Usually, this is accomplished by either by-passing some of the turbine flow around the highest performance system or by adding a control pressure drop between the turbines. The base case designs are such that the fuel turbopump establishes the turbine flow rate requirement at a value 5% to 10% higher than that required by the LOX turbine to allow for the control pressure drop.

The relative engine performance (I_{sp}) degradation contribution of fuel and oxidizer turbopumps is, therefore, a complex function of turbine pressure ratio and flow rate. The problem can be simplified to a manageable level by using the following assumptions:

- Similar performance changes can be made simultaneously in both fuel and LOX turbopumps.
- Such changes will always be made in the same (either improving or degrading performance) direction.
- Performance improvements or degradations of fuel and LOX turbopump alternatives are equal in terms of the turbine flow rate effect upon specific impulse.

It is recognized that these assumptions are not necessarily valid, but a comprehensive systems analysis defining the actual relative weighting factors was beyond the scope of the study. Thus, these assumptions allowed definition of the cost optimization methodology to proceed. A more rigorous systems analysis would be required for any future program using the methodology developed here.

The above reasoning allowed determination of the effect of design requirements variations upon component performance to proceed almost independently for the fuel and LOX turbopump subcomponents. It was not necessary to select complete propellant feed system level alternatives for study. The ensuing subsections describe this determination.

(a) Pumps

Dimensional variations up to and in excess of commonly specified tolerance bands were investigated to determine the resulting effects upon over-all pump efficiency and head rise. The surface quality or surface finish of important flow passages was varied over a wide range to assess friction losses and resulting effects upon pump performance. These effects were investigated for both the oxidizer and fuel pump, because of the characteristically different concept and method of fabrication between these pumps. Each investigation is reported separately.

1 Oxidizer Pump

Basically, this pump consists of a shrouded impeller and a volute type housing. Leakage is controlled by labyrinths on both impeller shrouds. The effects of the following parameters were investigated.

a Impeller Discharge Diameter

Variation of discharge diameter mainly affects pump head rise. In practice, this diameter is machined a few per cent larger to assure that the head requirement can be met without increasing speed. If necessary, the blades can be trimmed back to reduce head. In general, no matching or impeller-to-housing interaction problems will occur with a volute type housing at impeller discharge diameter variations of approximately 10%.

b Impeller Discharge Blade Height

The discharge blade height or port width mainly affects the discharge flow coefficient. Investigation of this effect was conducted using the pump design and loss isolation program developed for the NERVA turbopump project. Results indicate fairly flat efficiency versus flow coefficient curves for shrouded impellers. Performance is plotted as a function of blade height on Figure No. 67.

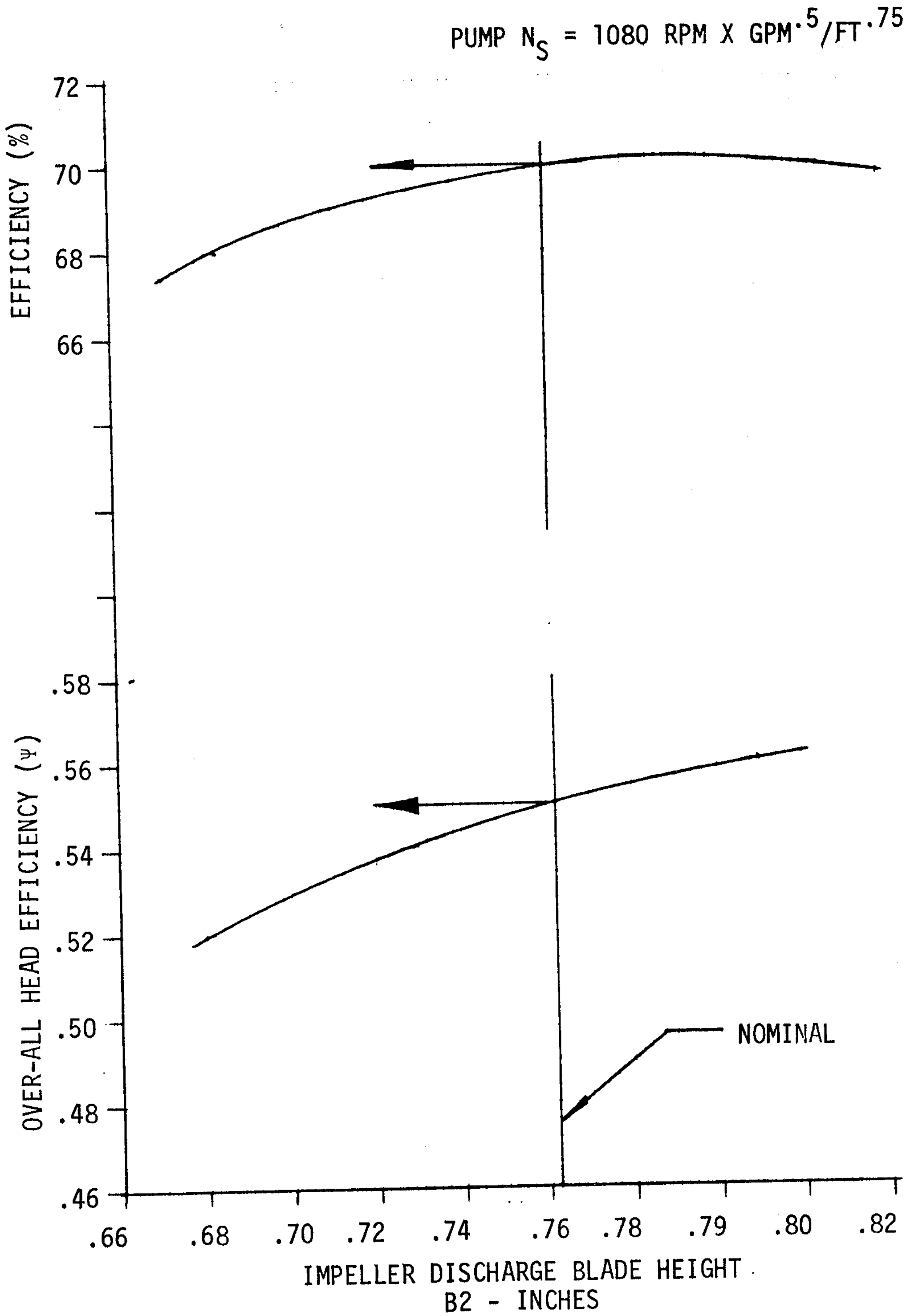


Figure 67. - Effect of Impeller Discharge Blade Height upon Pump Performance, LOX Pump

c Impeller Discharge Blade Angle

Impeller discharge angle variations as big as $\pm$ 5-degrees were considered. Inlet blade angle and discharge flow coefficient were assumed as constant. Thus, the configuration with the lowest discharge blade angle yielded the longest flow path and, therefore, friction loss. The configuration with the highest discharge angle had the lowest friction loss, but incurred a higher diffusion loss because of increased retardation of the relative flow. As a result, efficiency at both limits of vane angle is lower than at the nominal value. The head coefficient increases with increasing blade angle. Figure No. 68 depicts pump efficiency and head coefficient plotted as a function of the discharge blade angle.

d Effect of Surface Roughness

Surface roughness or surface quality effects were analyzed for impeller blade passages, the impeller disk and the volute housing. At high Reynolds numbers ($RE > 10^6$), skin friction essentially becomes a function of the relative surface roughness rather than that of the Reynolds number. Friction factors (f) for various surface qualities were determined with an expression recommended by the Gottingen Institute for granular surfaces:

$$f = \frac{1}{(2 \log (d/k) + 1.138)^2}$$

where (d/k) denotes the relative surface roughness defined as the hydraulic diameter of the flow passage divided by the surface finish. The range of relative surface roughness investigated extends from that of polished channels to that of corroded pipes. Figures No. 69 and No. 70 depict pump efficiency and head coefficient as a function of surface finish for the impeller and volute housing. Disc friction only affects the input head or pump efficiency. The friction factor used in the disc friction equation was varied from its nominal value according to the relative surface roughness analogous to the friction coefficient for channel flow. Results of this effect upon pump performance are shown on Figure No. 71.

e Labyrinth Dimensions

The leakage flow rate across the labyrinth determines the volumetric efficiency of the pump. The effect of radial clearance, tooth thickness, and tooth spacing upon the leakage flow was analyzed with the use of a computer program based upon G. Vermes Fluid Mechanics Approach complemented by annular orifice data from K. J. Bell and O. P. Bergelin. Leakage flow and efficiency are plotted versus the aforementioned parameters on Figures No. 72, No. 73 and No. 74. The radial clearance predominantly exerts the strongest effect, while tooth thickness and spacing have only little influence upon efficiency.

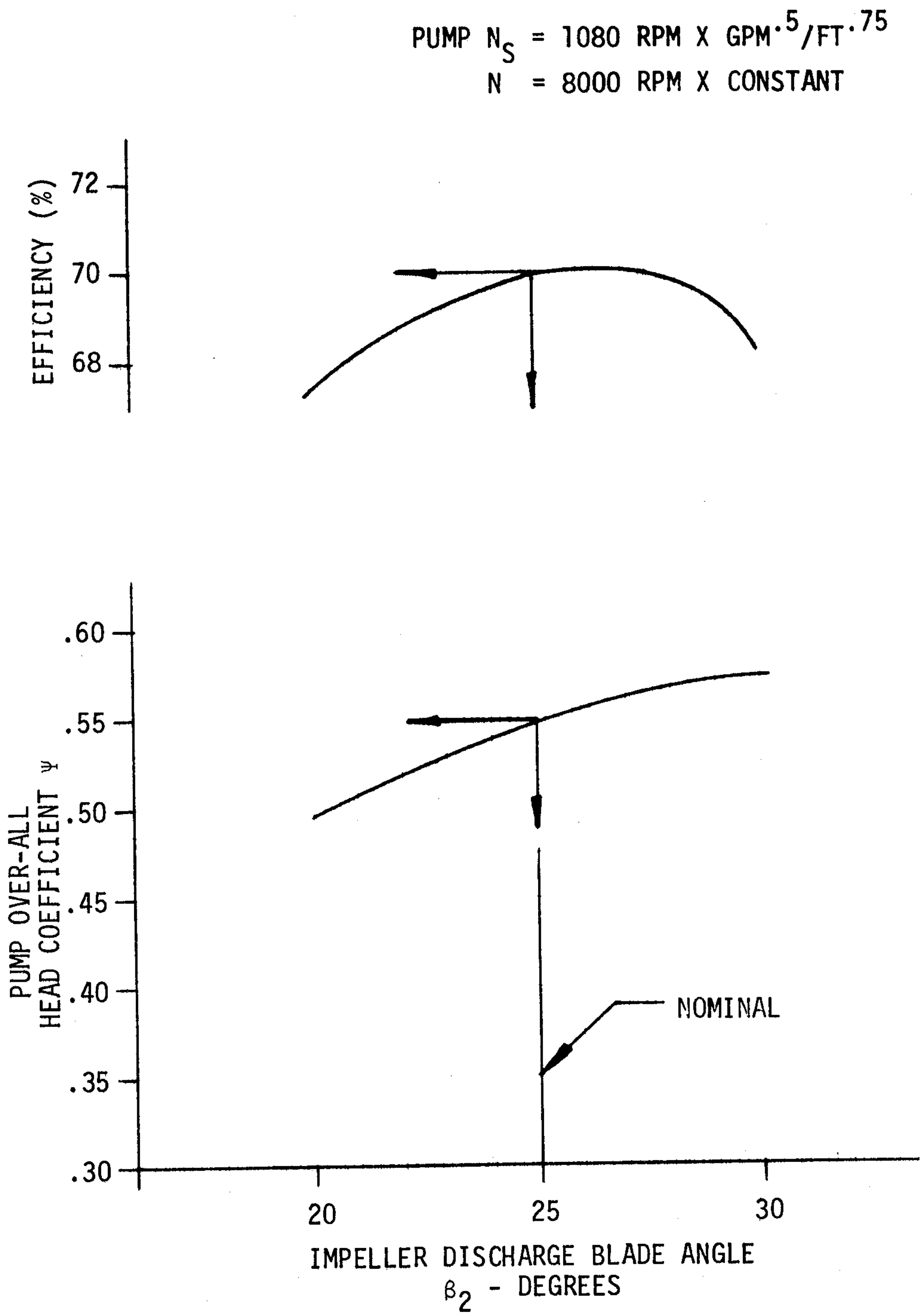


Figure 68. - Effect of Impeller Discharge Blade Angle upon Pump Performance, LOX Pump

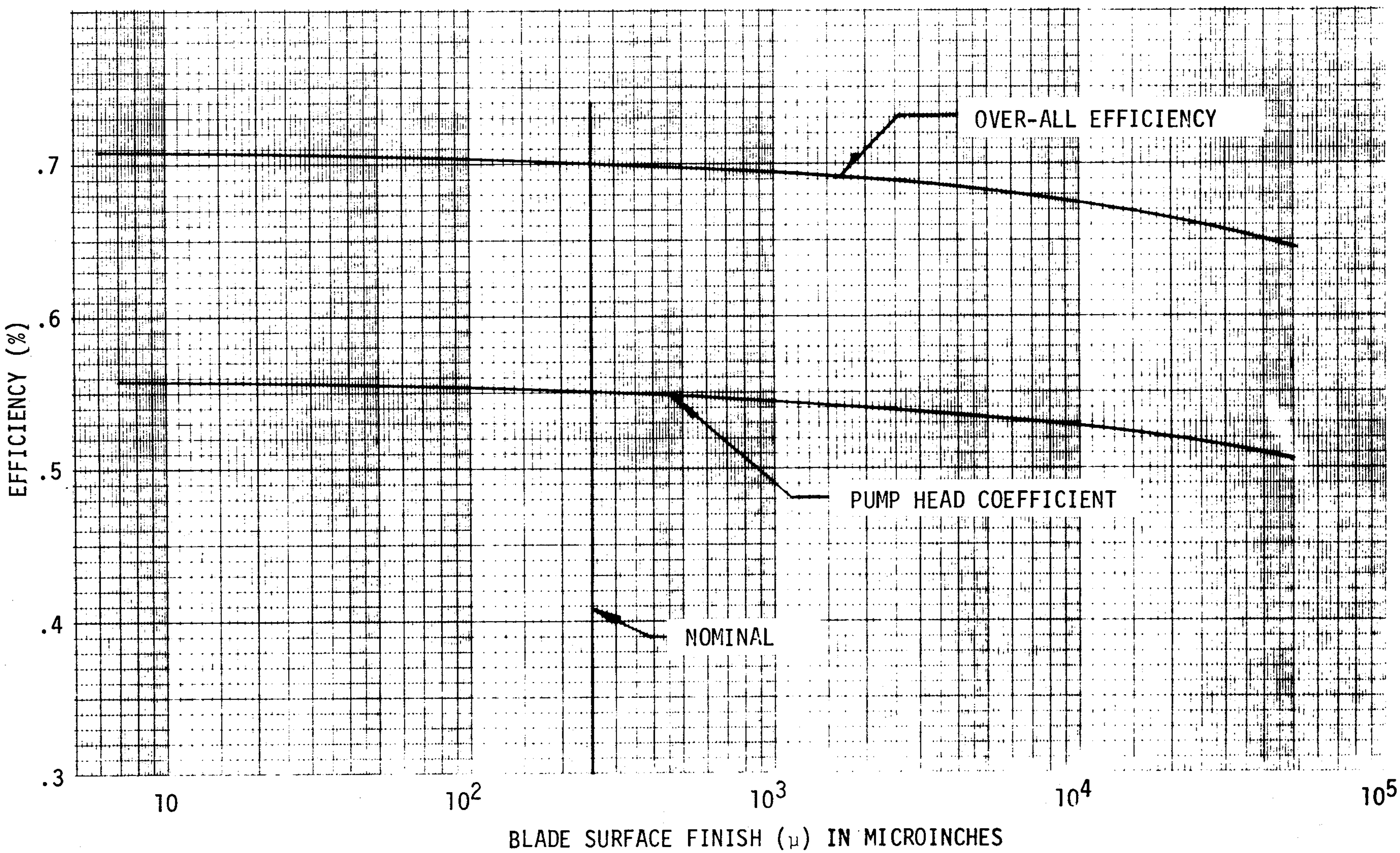


Figure 69. - Effect of Impeller Blade Surface Finish upon Pump Performance, LOX Pump

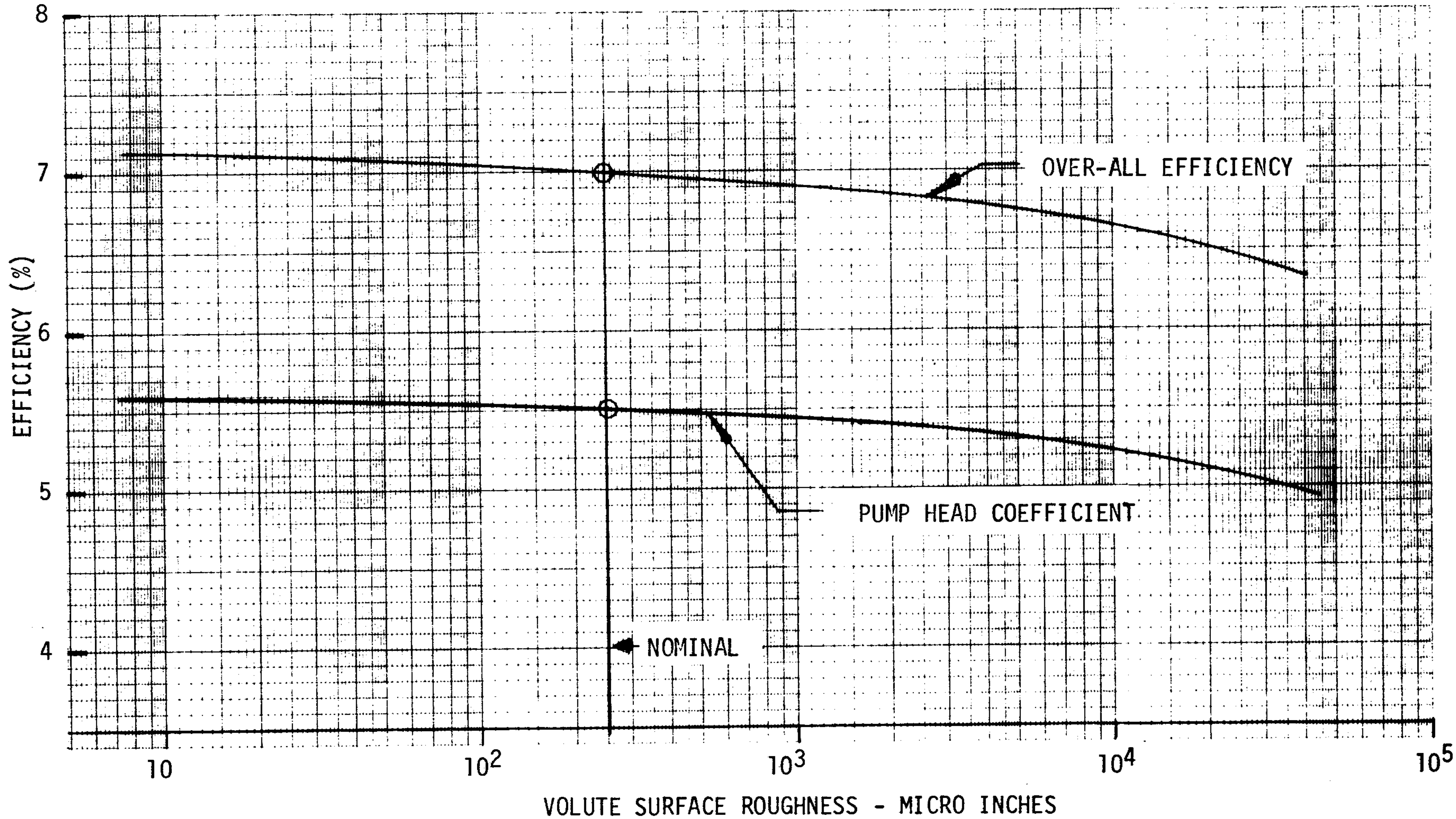


Figure 70. - Effect of Volute Surface Roughness upon Pump Performance, LOX Pump

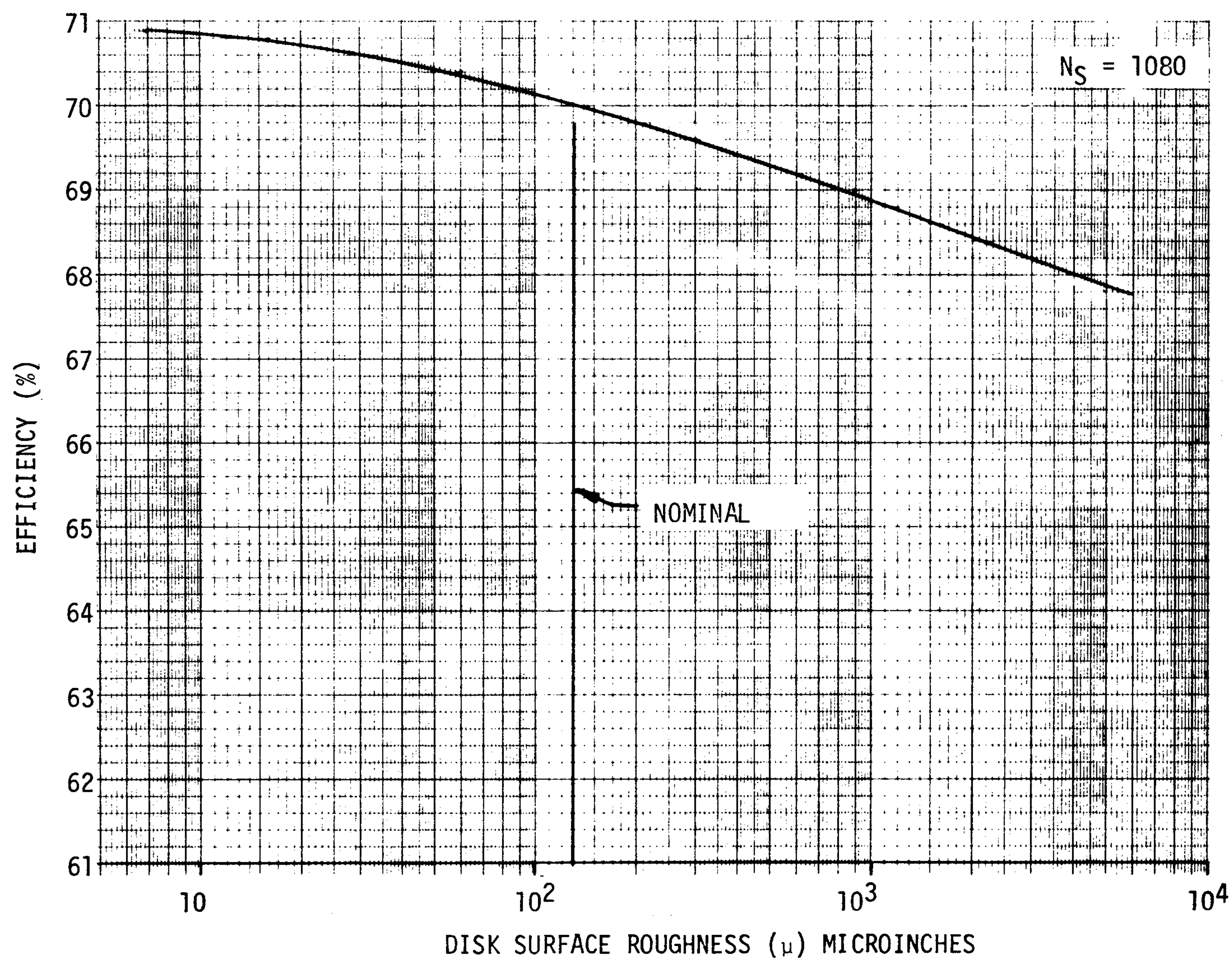


Figure 71. - Effect of Disk Surface Finish upon Pump Performance, LOX Pump

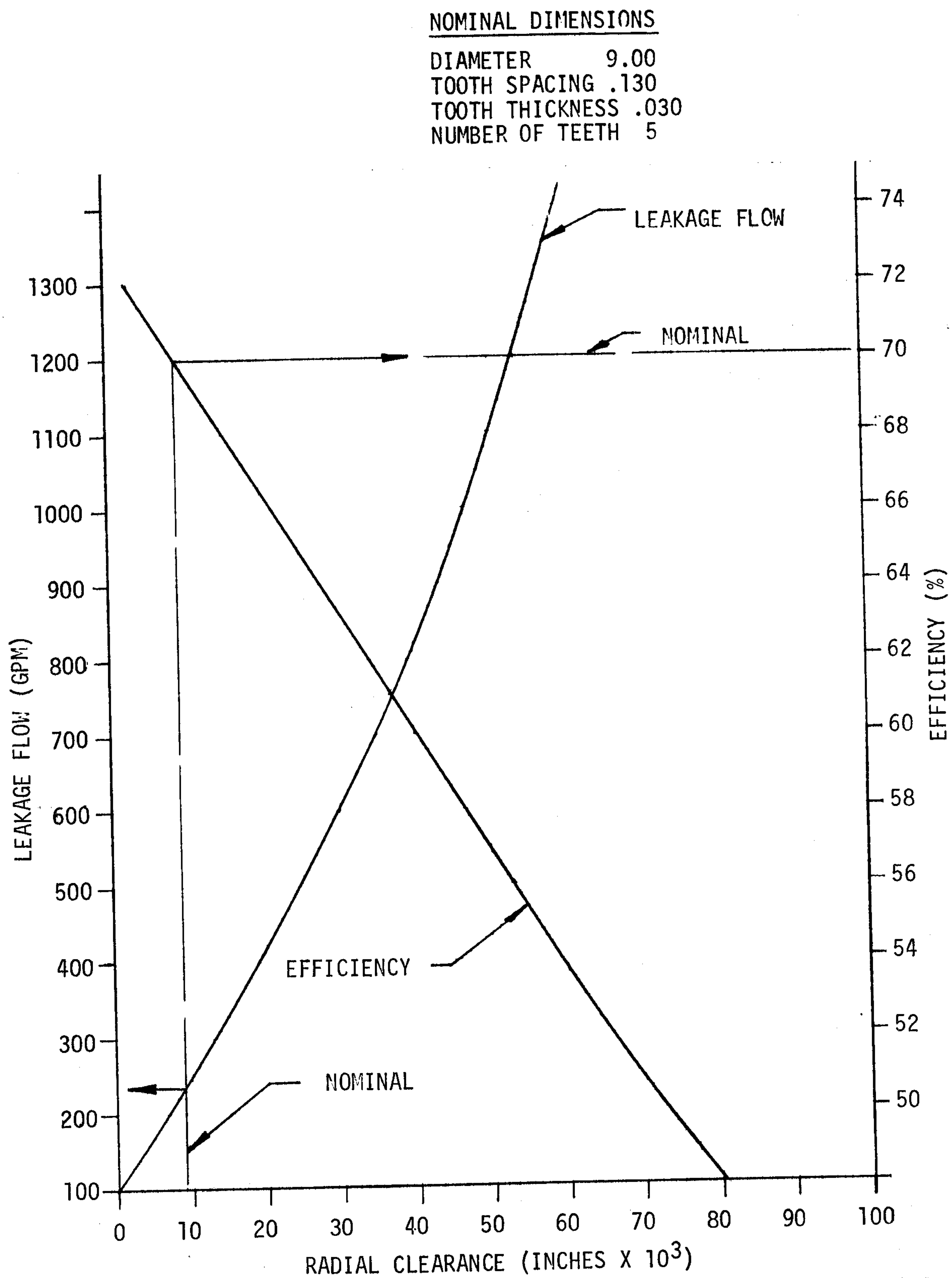


Figure 72. - Effect of Labyrinth Front Shroud Clearance upon Over-All Pump Efficiency, LOX Pump

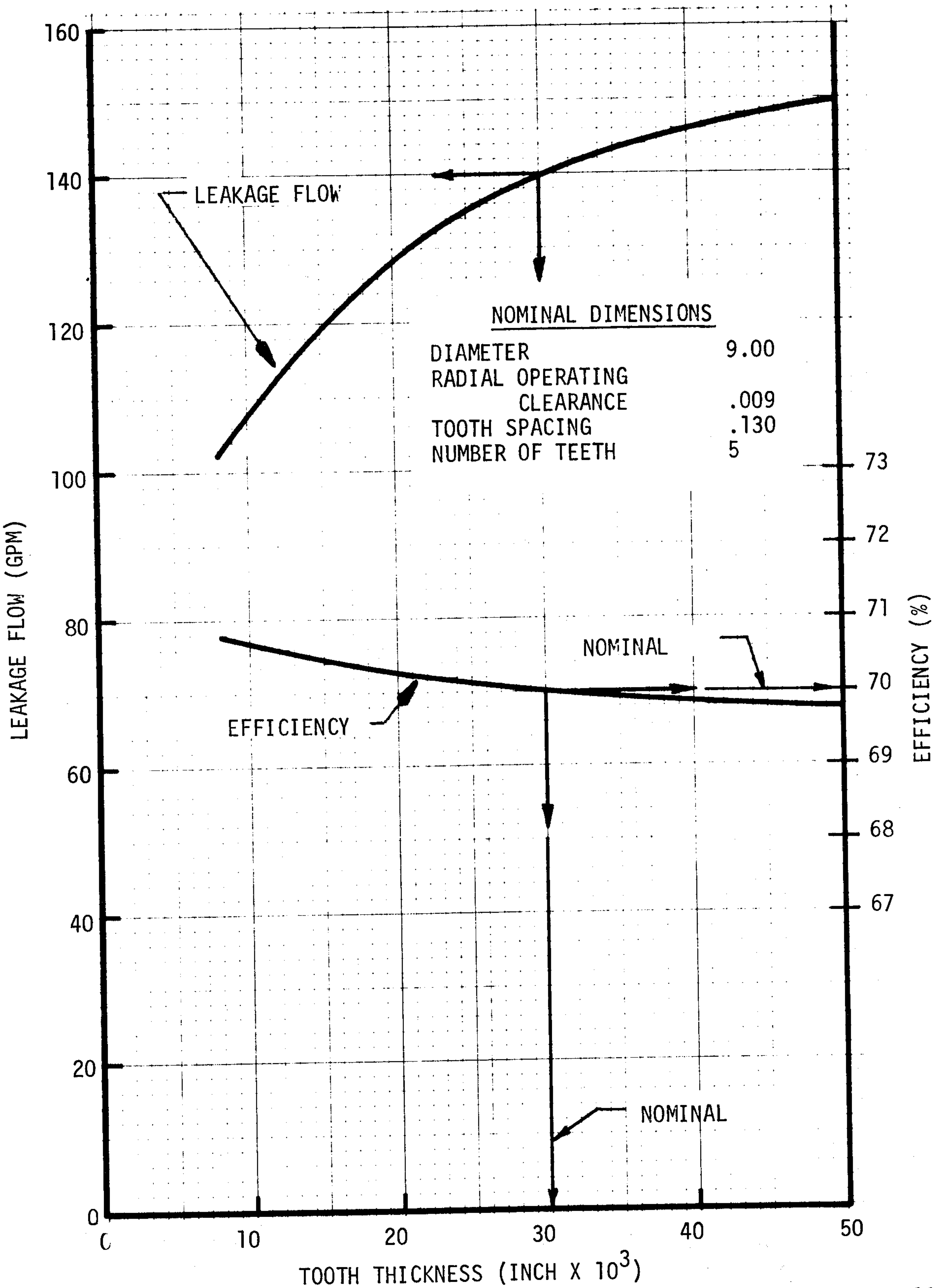


Figure 73. - Effect of Labyrinth Front Shroud Tooth Thickness upon Over-All Pump Efficiency, LOX Pump

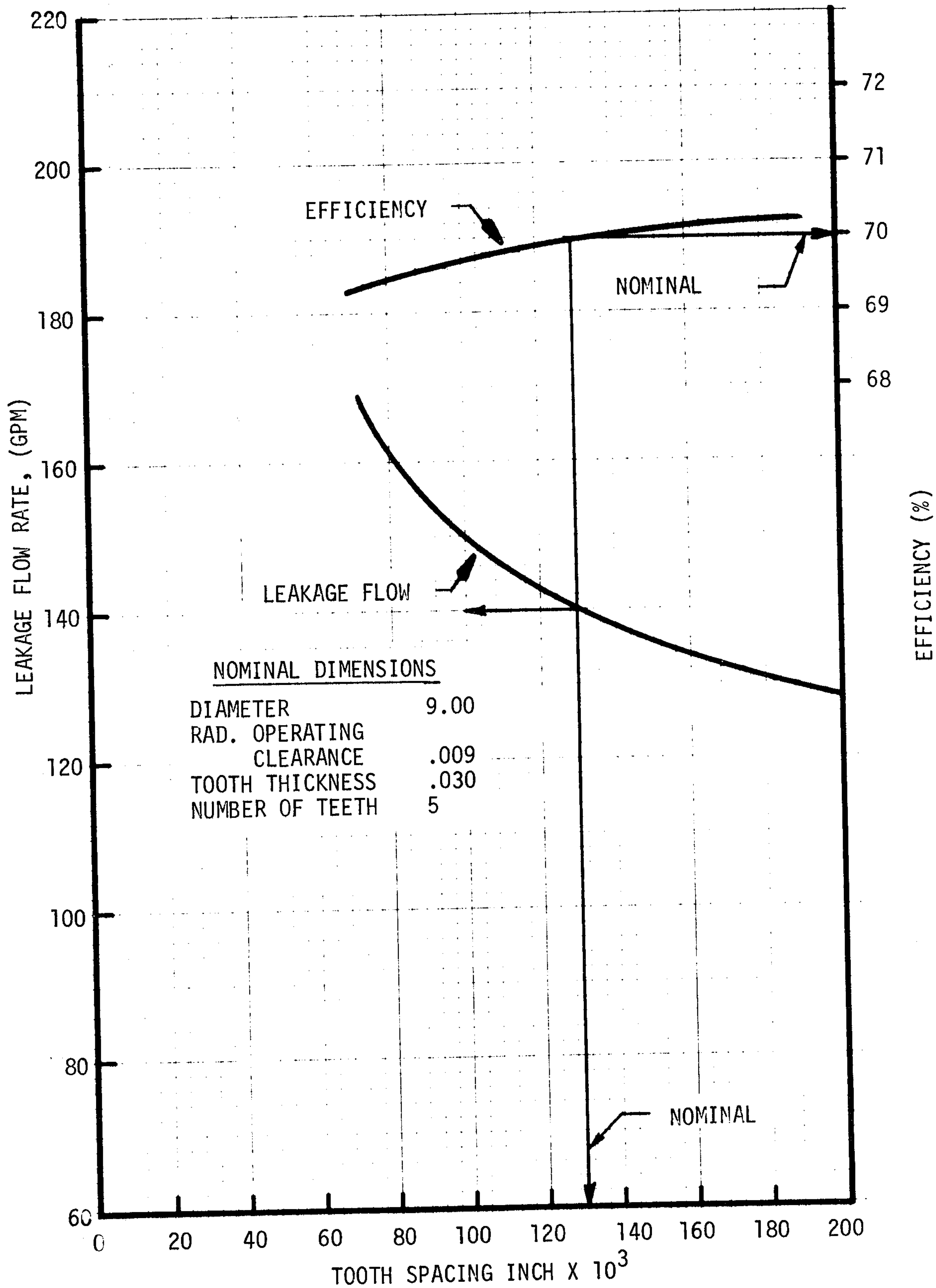


Figure 74. - Effect of Labyrinth Front Shroud Tooth Spacing upon Over-All Pump Efficiency, LOX Pump

f Pumps at Constant Suction Specific Speed

A family of impellers of constant suction specific speed (43,000 rpm x $gpm^{0.5}/ft^{0.75}$) was sized to compare impeller discharge geometry and rotational speed for various inlet diameters. The Net Positive Suction Head (NPSH) was established at three times the inlet axial velocity head and the inlet blade angle at 1.74 times the fluid angle (incidence to blade angle ratio = 0.425) for all cases investigated. The pertinent parameters of these pumps are plotted versus the inlet diameter on Figures No. 75 and No. 76.

2 Fuel Pump

This pump is composed of an unshrouded impeller and a diffusion type housing with rolled-over volute. The following parameters were investigated.

a Impeller Discharge Diameter

Because of the vaned diffuser, the off-design performance of this pump will be more sensitive to diameter changes (e.g., ±5%) than the oxidizer pump which is fitted with a volute housing. However, within reasonable limits, the technique of diameter trim discussed for the oxidizer pump can be applied to this pump as well.

b Impeller Discharge Blade Height

At a constant axial clearance, tip clearance losses will increase with decreasing blade height. Thus, the unshrouded impeller will be more sensitive to blade height variations than the shrouded impeller of the oxidizer pump. Efficiency and head coefficient are plotted versus impeller discharge blade height on Figure No. 77. Impeller-housing interactions for the ±10% dimensional variation were neglected.

c Impeller Discharge Blade Angle

Considerations and results of this investigation are similar to that of the oxidizer pump. Because this impeller has machined blades, the range of blade angle variation was reduced to ± 2-degrees from the nominal value. Figure No. 78 presents the pump performance as a function of blade angle.

d Diffuser Blade Inlet Angle

The diffuser blade was assembled to retain its general shape and orientation while the inlet angle was varied. In this way, changes in blade inlet angle only affect blade camber in the inlet region. Fluid turning and diffusion within the blade passage increase

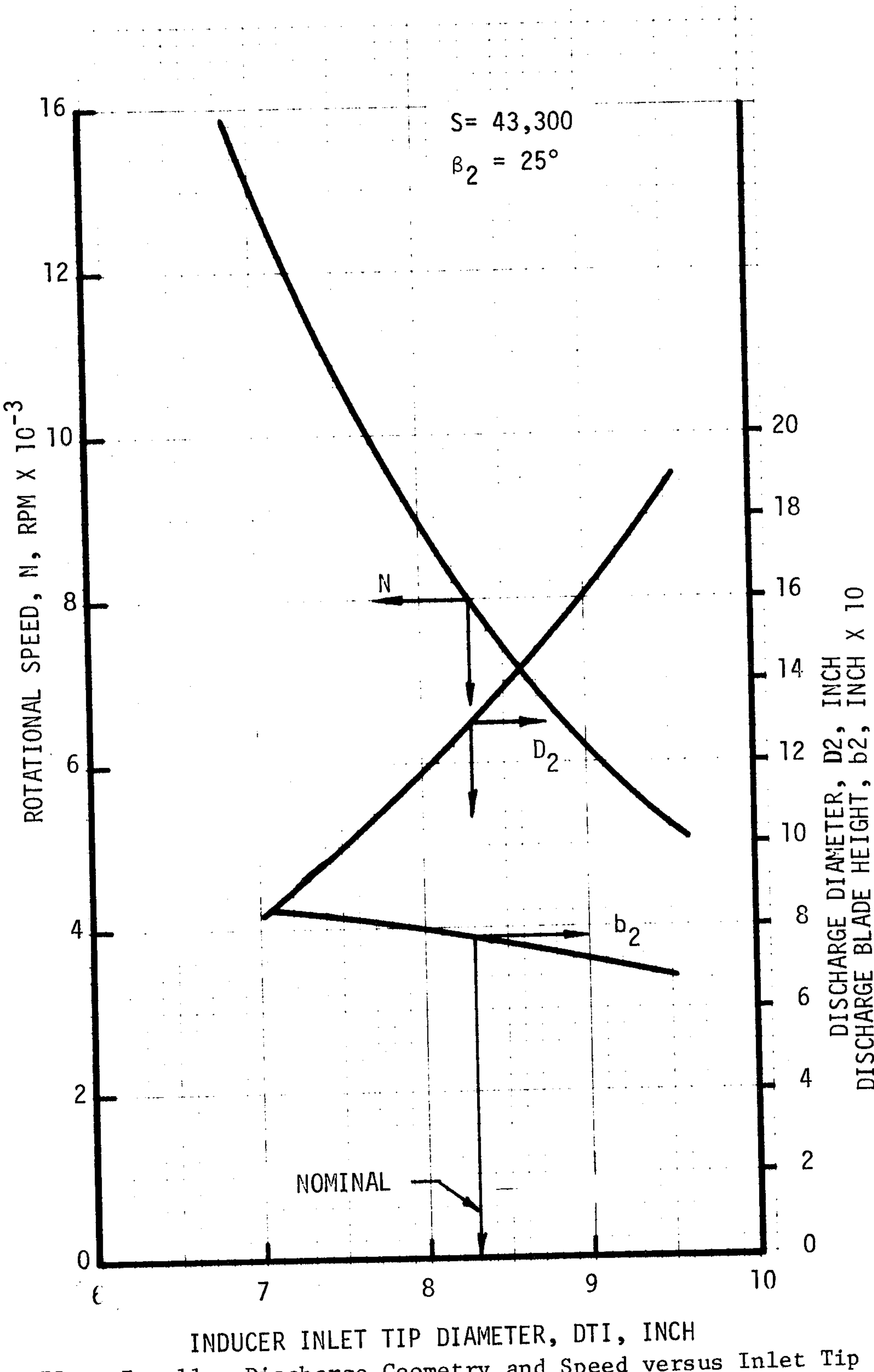


Figure 75. - Impeller Discharge Geometry and Speed versus Inlet Tip Diameter DTI for Pumps of Constant Suction Specific Speed, LOX Pump

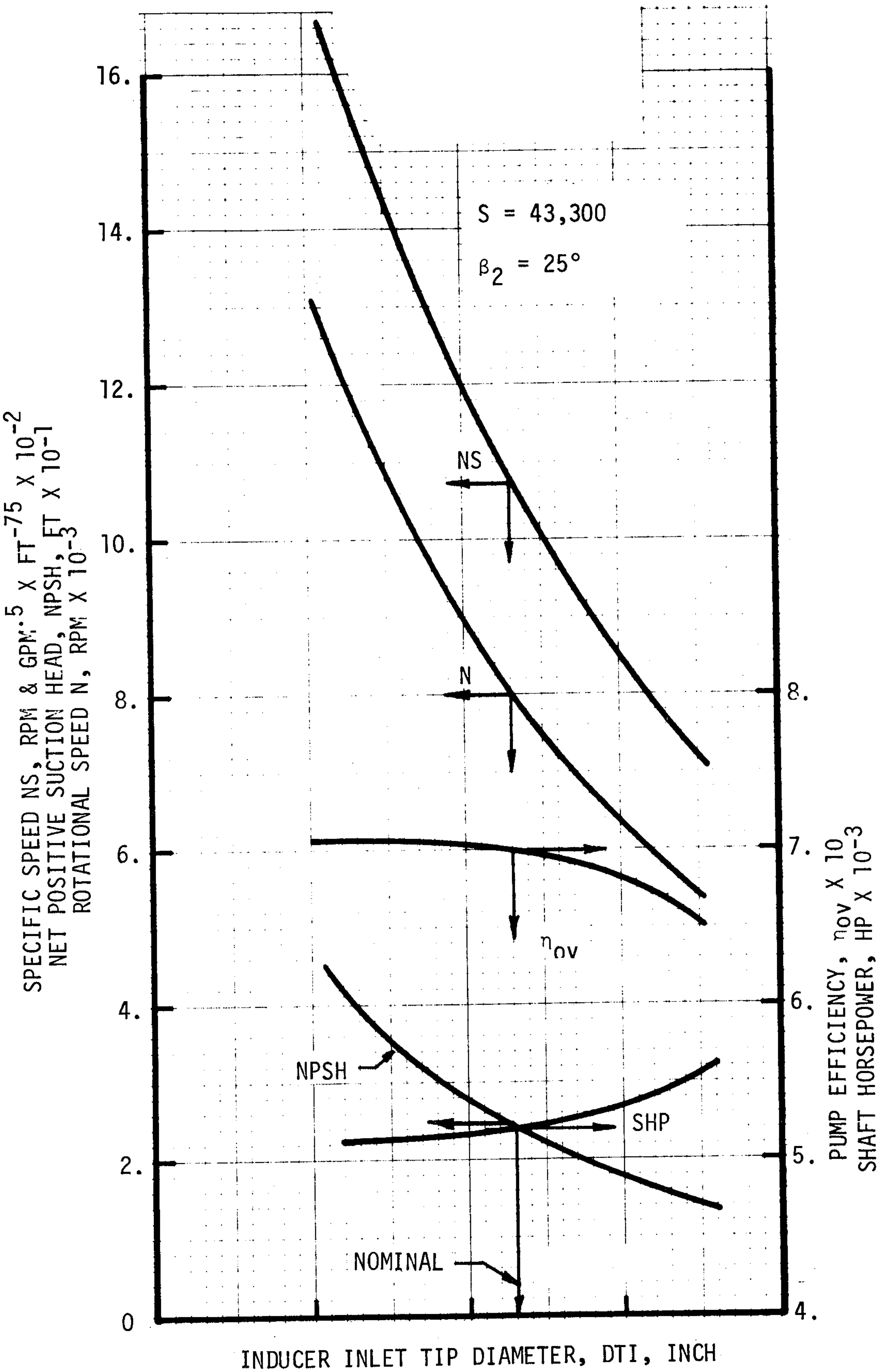


Figure 76. - Power Requirements and Speed as a Function of Inlet Diameter for Pumps of Constant Suction Specific Speed, LOX Pump

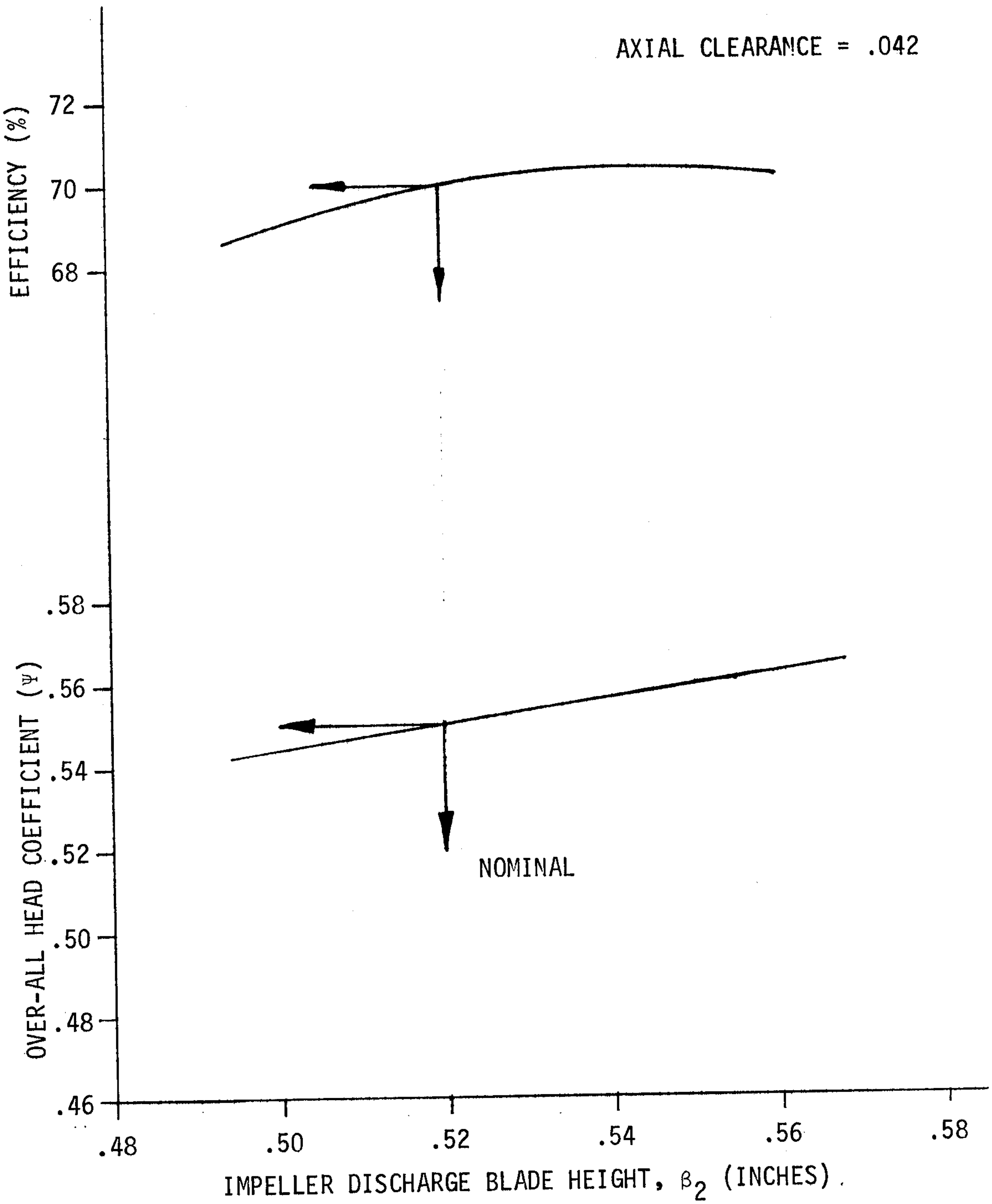


Figure 77. - Effect of Impeller Discharge Blade Height upon Pump Performance, Fuel Pump

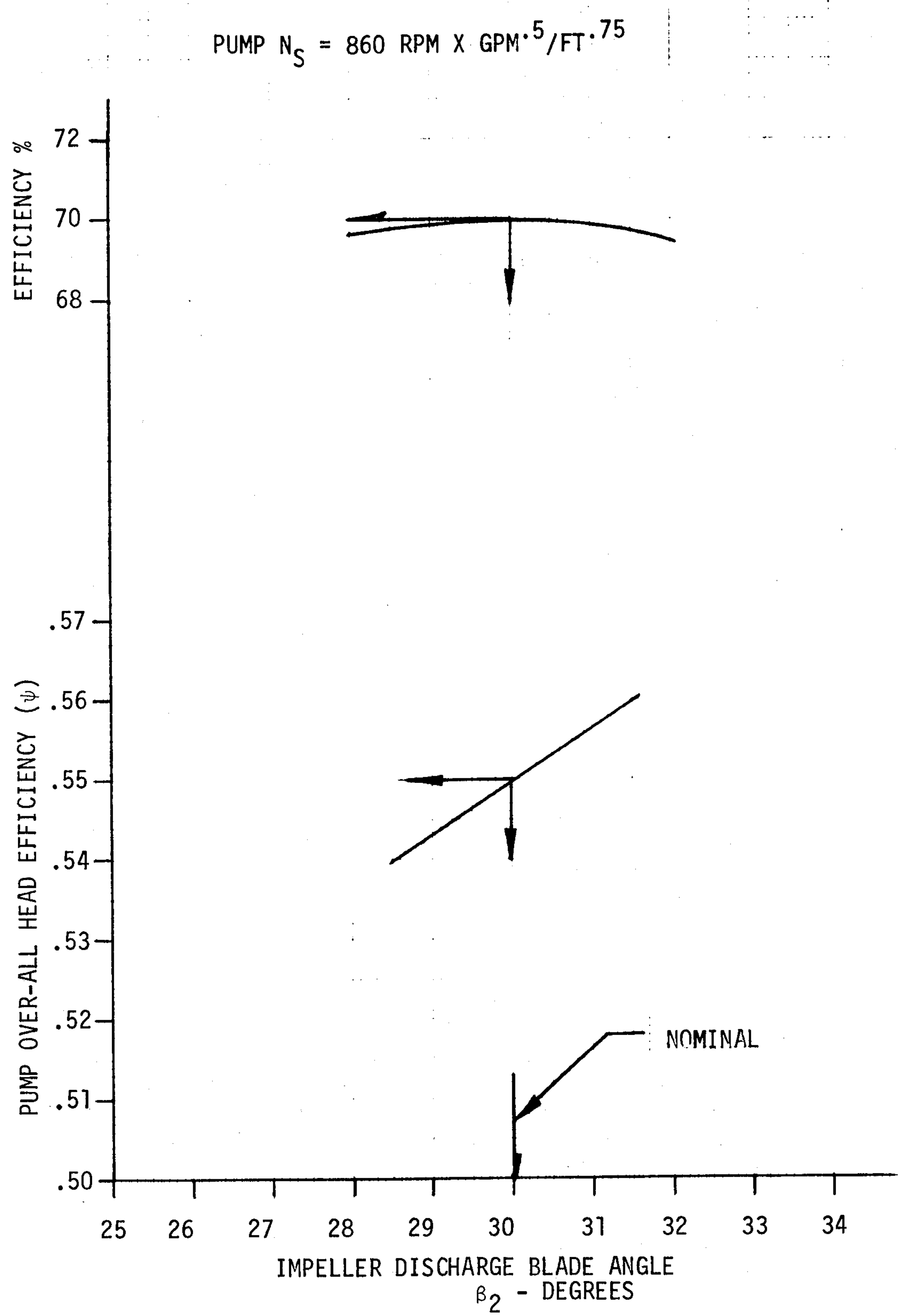


Figure 78. - Effect of Impeller Discharge Blade Angle upon Pump Performance, Fuel Pump

as the blade angle, the diffusion losses diminish considerably but incidence losses result in slightly increasing total blade losses. Friction losses are constant over the entire range of inlet angles investigated. The effects upon pump efficiency and head coefficient are shown on Figure No. 79.

<u>e</u> Blade Tip Clearance

Performance of an unshrouded impeller is quite sensitive to the blade tip clearance. An approximate method, based upon experimental data, to assess tip clearance losses was used in the analysis. The impeller blade height was kept constant for the entire range of tip clearances investigated. Results are presented in terms of efficiency and head coefficient on Figure No. 80. Headrise and efficiency generally are subject to the same percentage variations, from zero to clearance to blade height ratios (s/b) of approximately 0.08. At greater values of s/b, Titan pump tests indicated that the head coefficient drops off more rapidly.

<u>f</u> Impeller Blade Surface Finish

Head coefficient and efficiency are plotted as a function of surface finish on Figure No. 81. This effect is similar to that investigated for the oxidizer pump. Because the impeller blades are machined, the upper limit of surface roughness investigated was established at 1000 microin.

<u>g</u> Pumps at Constant Suction Specific Speeds

Based upon the ground rules selected for the analysis of the oxidizer pump, a family of impellers of constant suction specific speed was sized to relate pump geometry and rotational speed to the inlet diameter. Parameters of interest are plotted as a function of impeller inlet diameter on Figure No. 82.

(b) Turbines

The LOX and fuel turbine designs were evaluated to determine the effects of mechanical design requirements upon the gas flow rate needed. Surface finish and dimensional control of the flow passages were varied over a wide range to obtain performance effects. The design speed of the turbines was varied by a ratio exceeding 2 to accommodate a constant pump suction specific speed. The resulting changes in tip diameter, blade height, and gas flow rate are noteworthy.

Effects were investigated for both LOX and fuel turbines because they are characteristically different in concept. Each investigation is reported separately.

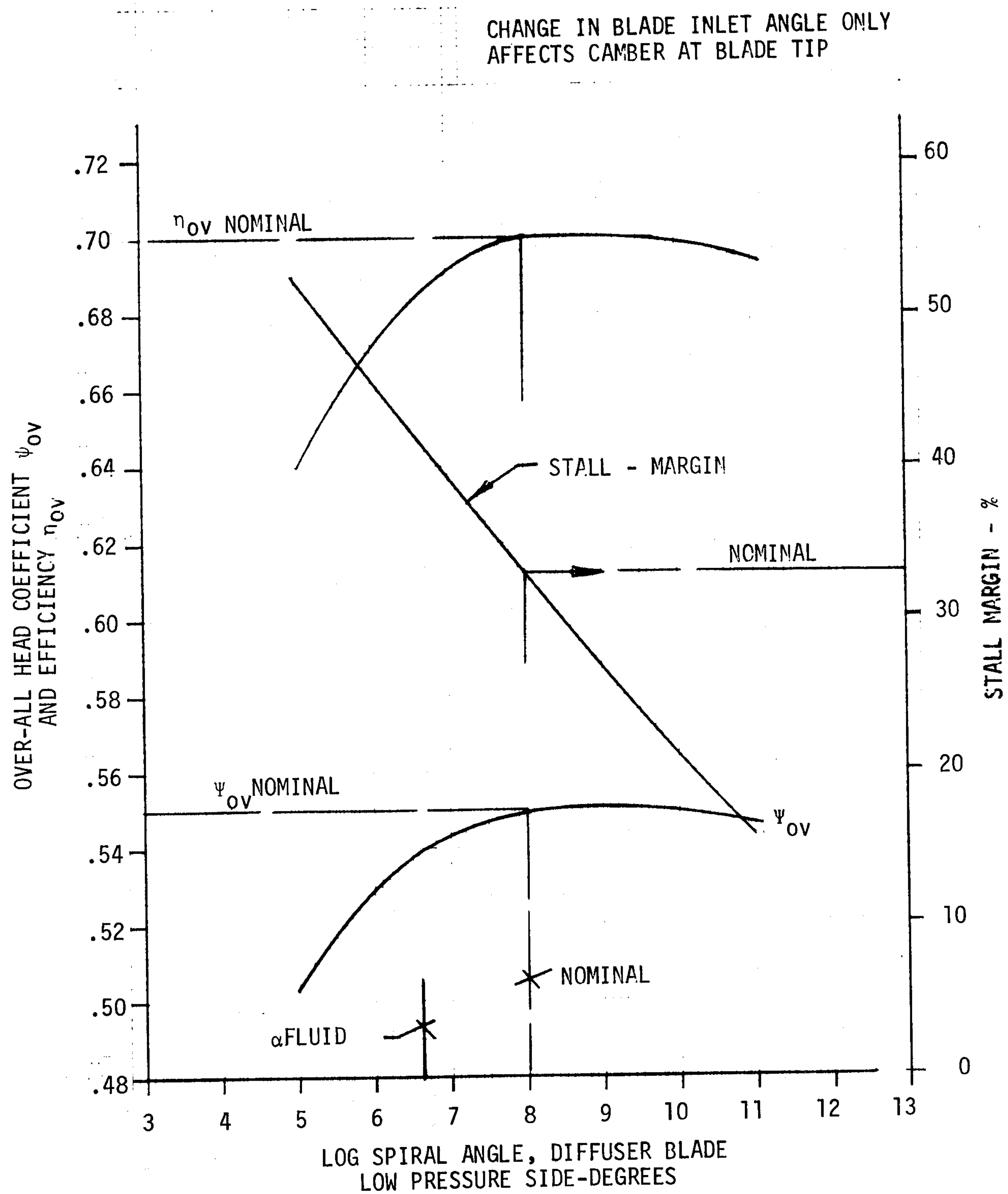


Figure 79. - Effect of Diffuser Inlet Blade Angle upon Pump Performance, Fuel Pump

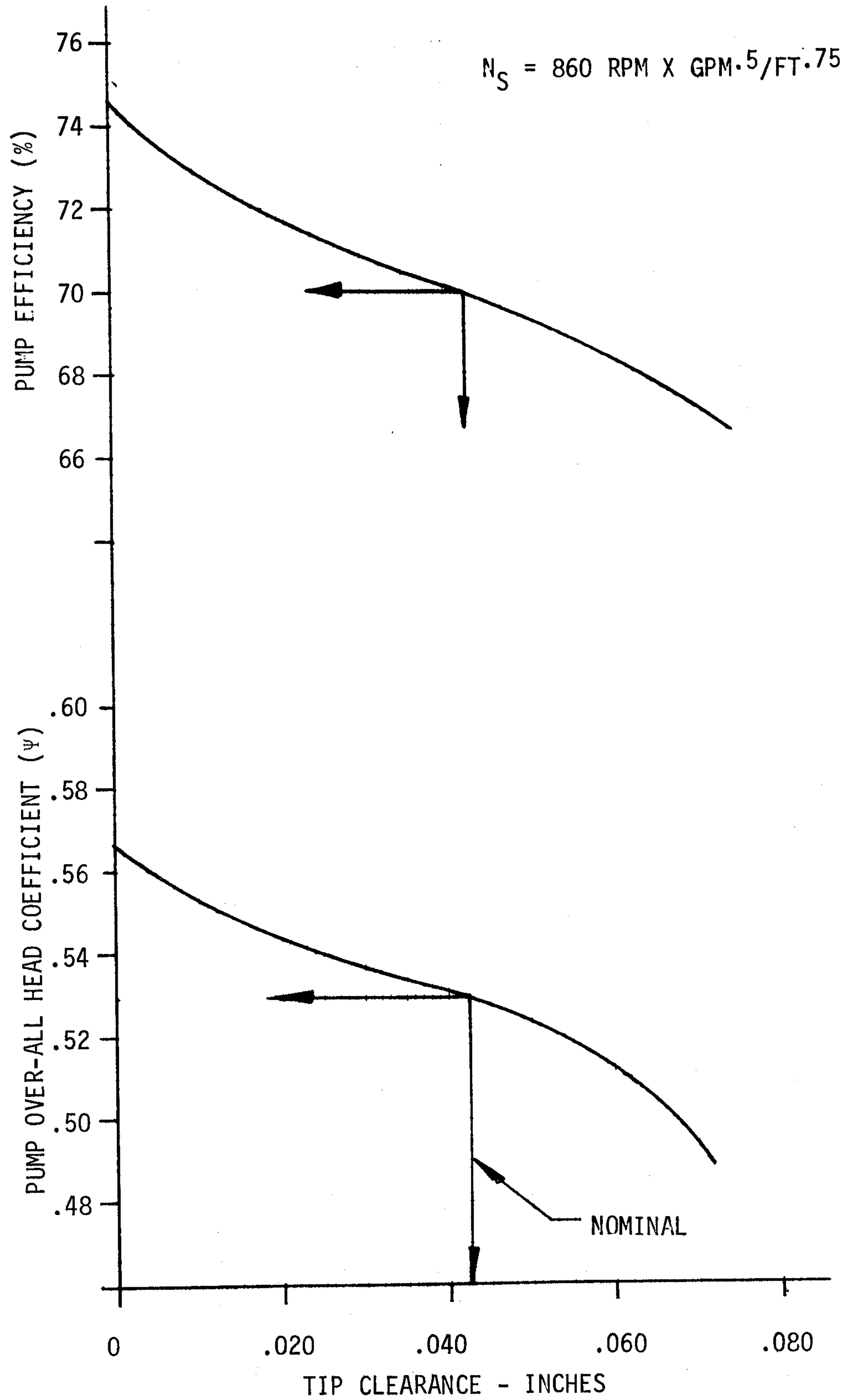


Figure 80. - Effect of Impeller Blade Tip Clearance upon Pump Performance, Fuel Pump

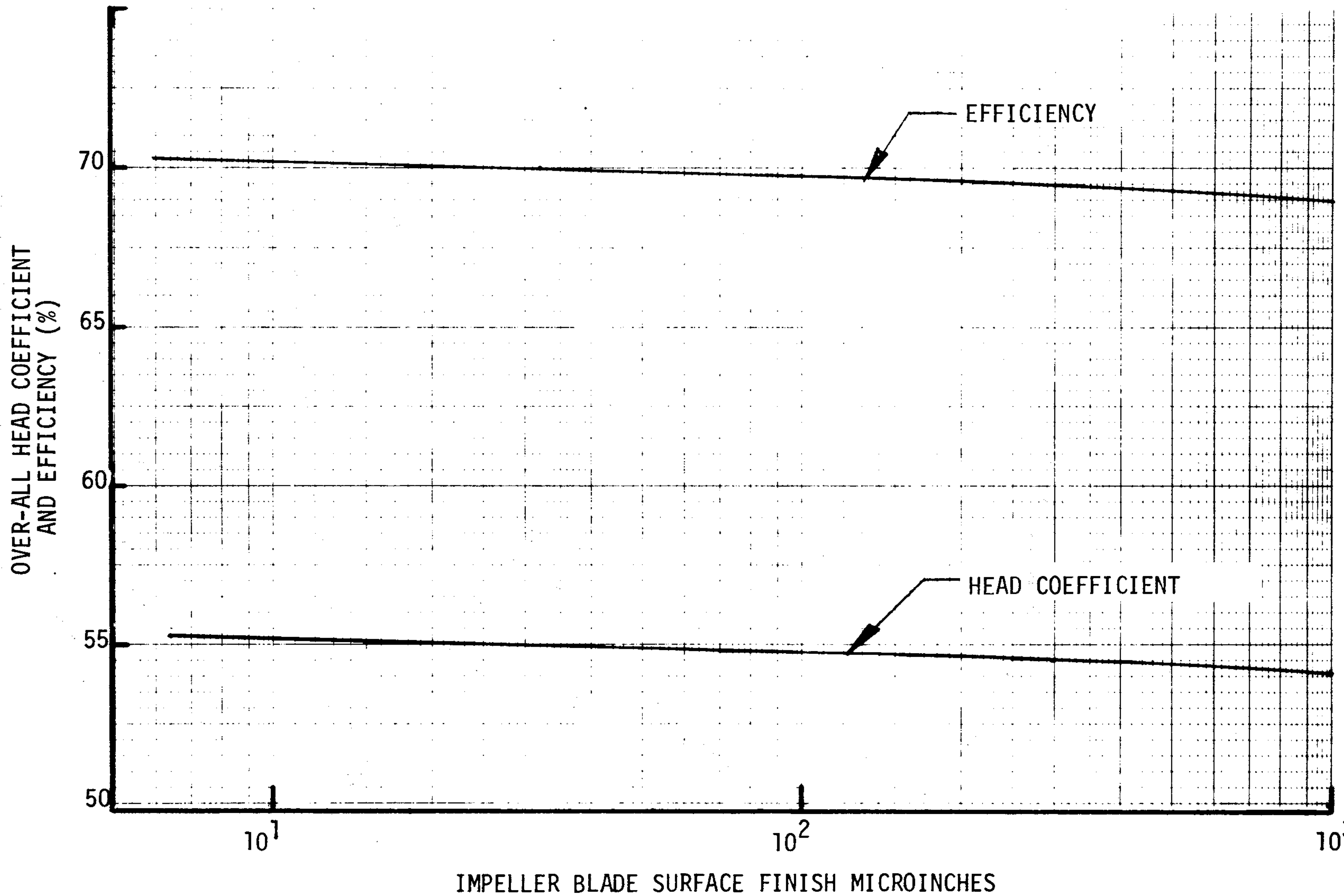


Figure 81. - Effect of Impeller Blade Surface Finish upon Pump Performance, Fuel Pump

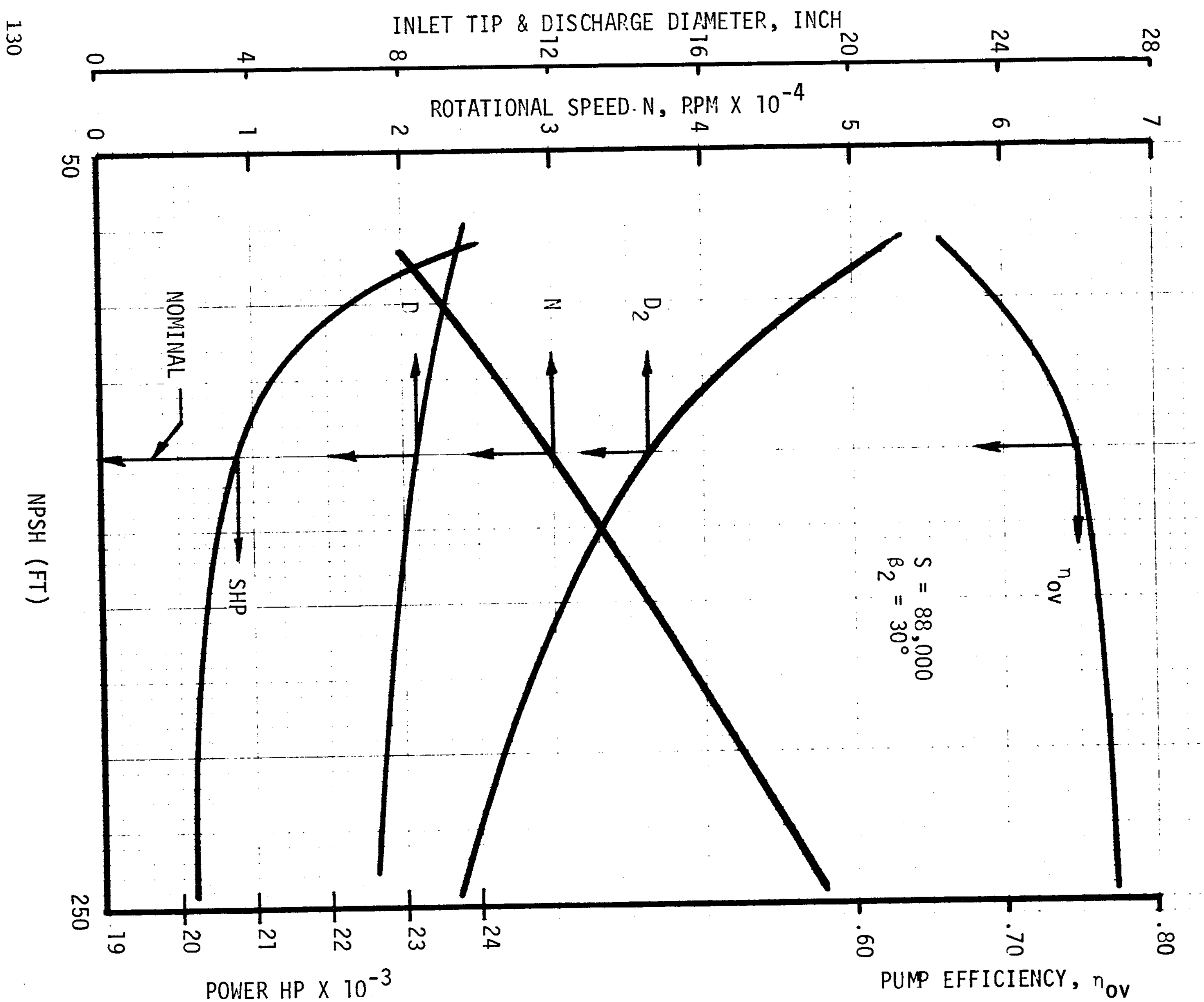


Figure 82. - Pump Parameters versus NPSH for Pumps of Constant Suction Specific Speed, Fuel Pump

1 Oxidizer Turbine

The turbine is a large (D_m = 17.2-in.) single-stage, impulse type, propelled by the combustion products of LO_2 and LH_2. The turbine is downstream and operates in series with the fuel turbine.

a Nozzle Vane Angle

The nozzle exit angle was deviated up to 9-degrees from the design point giving a maximum variation of 16% to propellant flow. Turbine flowrate versus nozzle angle deviation is shown on Figure No. 83. The speed, temperature, and power were assumed constant.

b Rotor Blade Angle

An incidence loss is incurred for deviations in the inlet angle of a rotor blade. Exit angle deviations cause a similar performance loss. Combined inlet and exit angle variations of up to 10-degrees were investigated. The maximum variation caused an increase in propellant flow of 12.5%. The losses incurred by rotor blade angle deviations are shown as flow-rate increases on Figure No. 83, along with the nozzle losses.

c Flow Passage Surface Finish

Performance losses caused by flow passage roughness were approximated by use of a technique based upon Moody's friction loss formula for pipes.

The friction losses from rough surfaces are minimal giving a flow increase of 2% for a nozzle surface roughness of 2000 microin. Plots of surface finish versus increased flow-rate for the nozzle and rotor are shown on Figure No. 84.

d Rotor Blade Tip Clearances

Turbine rotor blade tip clearance losses vary directly with the radial gap controlled by fabrication and assembly tolerances. The following additional parameters must be considered when comparing different types of turbines.

High hub-to-tip ratio rotors have greater losses than low hub-to-tip ratio rotors. The higher efficiency turbines are more sensitive to increased tip clearances. Honeycomb and sponged-metal perimeter inserts allow smaller clearances without the risk of rubbing failures. Shrouded rotors have smaller losses than open ended blades.

Turbine efficiency loss and turbine flow increase as a function of blade radial gap, for the plain unshrouded blades of the base case machine, are shown on Figure No. 85.

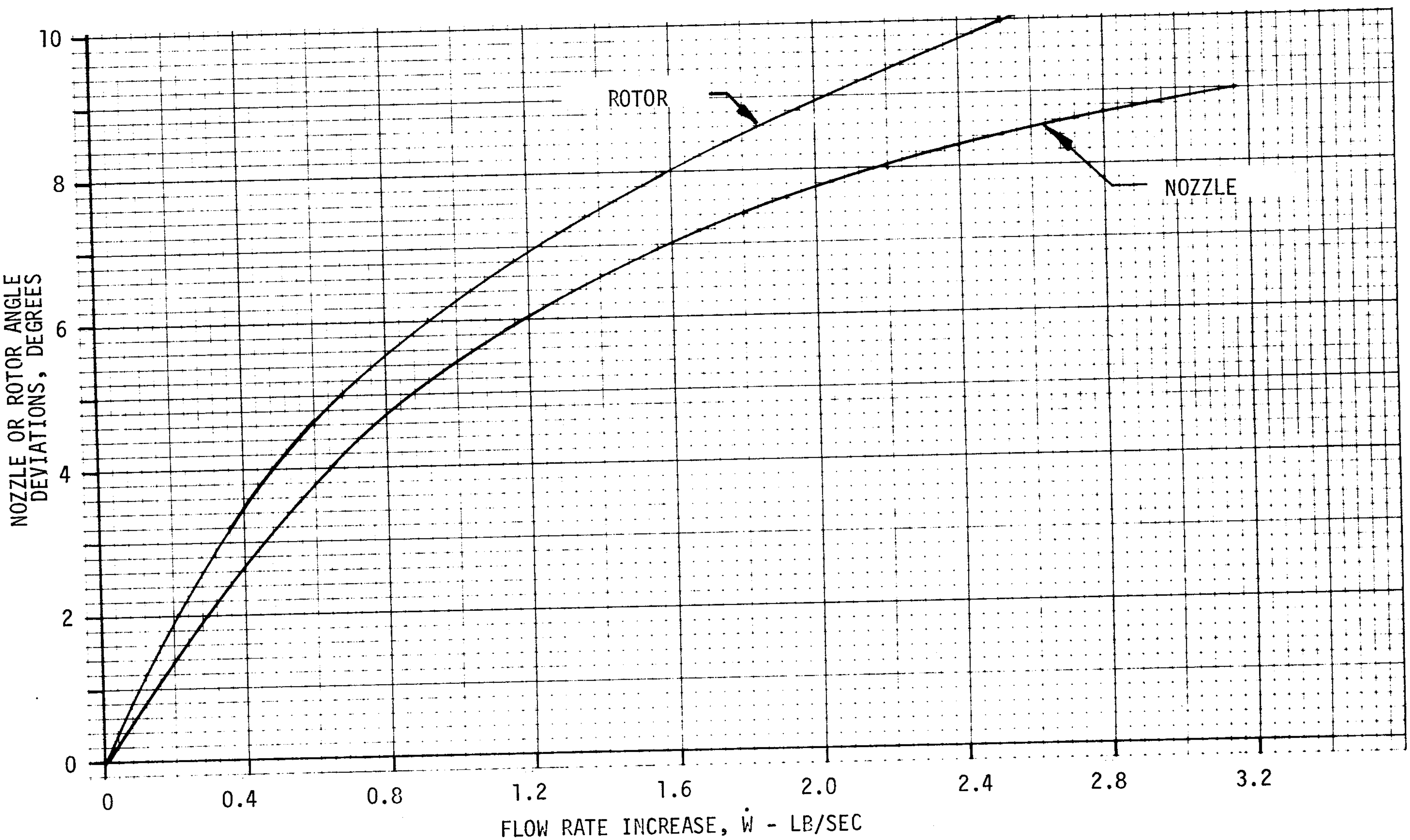


Figure 83. - Effect of Nozzle and Rotor Angle upon Flow Rate, LOX Turbine

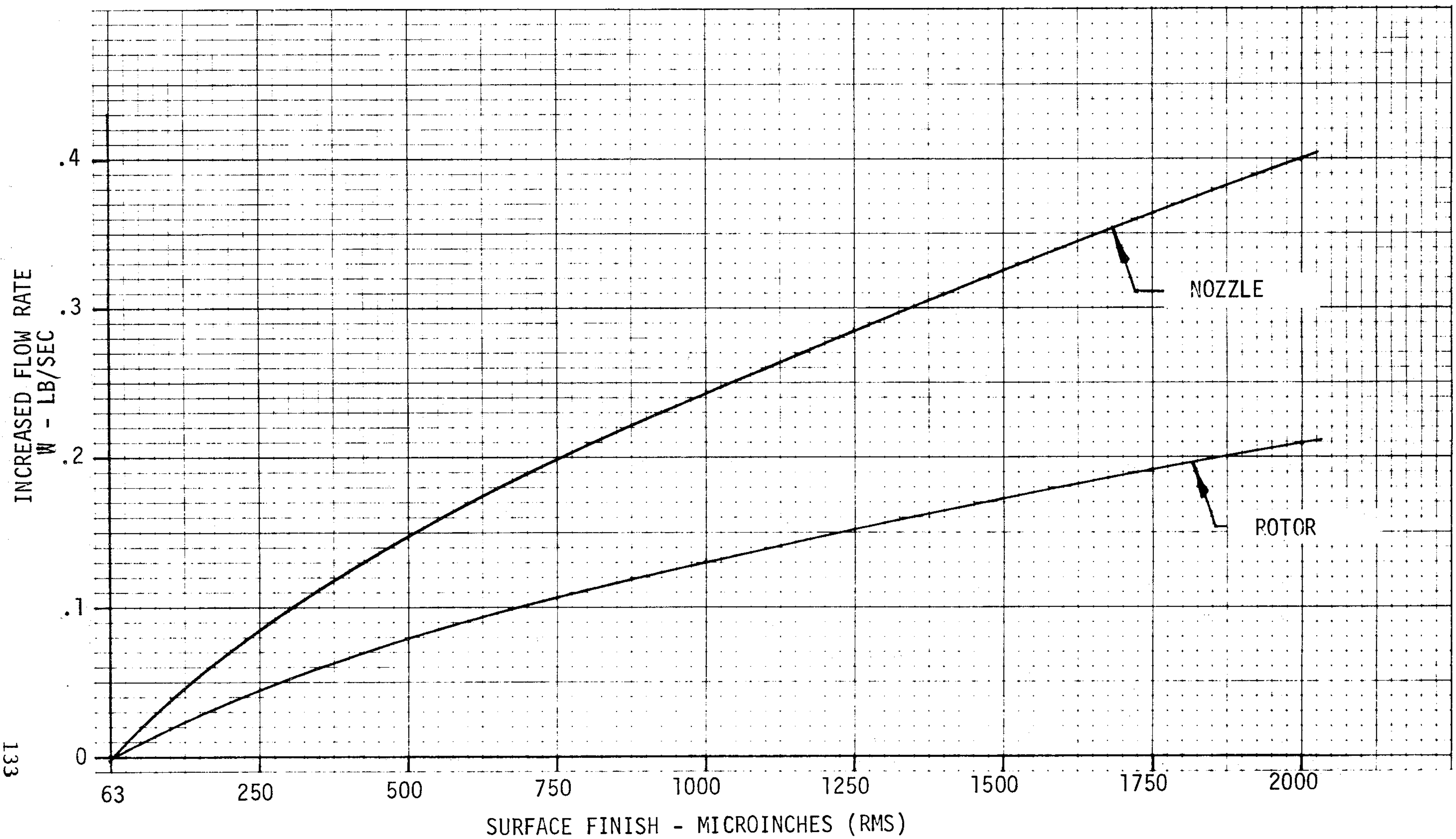


Figure 84. - Effect of Surface Finish upon Flow Rate, LOX Turbine

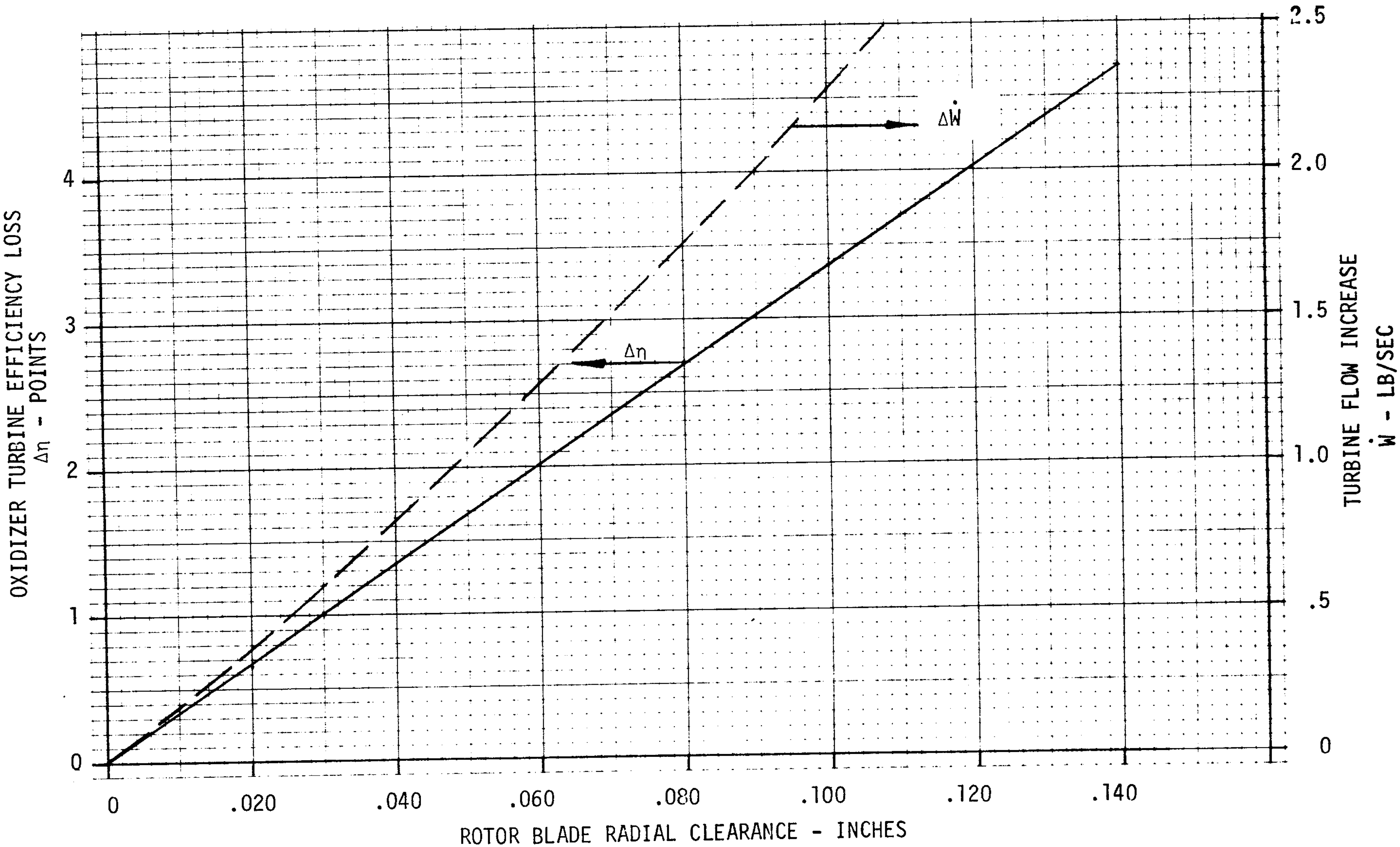


Figure 85. - Effect of Tip Clearance upon Efficiency and Flow Rate, LOX Turbine

e Rotational Speed Variation

Turbine rotor tip diameter, blade height and propellant flow-rate were investigated to determine how they varied with design point speed changes. This investigation was carried out in conjunction with the pump NPSH-size evaluation. The results were obtained by designing a turbine to satisfy each of the pump speed and power requirements.

Turbine flow rate, turbine rotor tip diameter, and rotor blade height are plotted versus pump NPSH on Figure No. 86.

2 Fuel Turbine

The fuel turbine is a two-row, Curtis staged, overhung system operating in series with the oxidizer turbine. In addition to the parameters investigated for the oxidizer turbine, the fuel turbine was optimized with respect to gas temperature versus blade root stress.

a Turbine Gas Temperature

The turbine gas temperature was varied over the range from 1200°F to 1500°F in increments of 100°. The blade height was varied to maintain the root stress at a constant safety margin with the temperature degraded material properties by increasing the turbine gas density. Shaft horsepower, rotational speed, and blade speed were assumed constant. Turbine flow requirements could be reduced by approximately 4% at the maximum gas temperature investigated using Inconel 718 material properties. A plot of turbine gas temperature versus flow rate improvement is shown on Figure No. 87. Effects of disc stress margin were not quantitatively investigated, but constant shaft critical speed margin (constant overhung mass) would require that blade speed be reduced. Extensive studies conducted for NERVA (Contract SNP-1) of very similar machines have indicated that minimum turbine flow rate occurs at 1200° to 1300°F.

b Nozzle Vane Angle

The first nozzle and second row turning vane exit angle deviation were evaluated based upon the changes in tangential velocity, Vu. The maximum angle deviation of 8-degrees at the first-stage nozzle caused an increased turbine flow rate of 17%. The same deviation of the second row turning vane only increased the flow rate by 4%. Turbine flow rate versus nozzle angle deviation is shown on Figures No. 88 and No. 89.

c Rotor Blade Angle

The rotor blade angle deviation causes a loss similar to the nozzle angle deviation. This loss was estimated by assuming that the velocity components, which are normal to the blade velocity, are completely lost. The inlet and exit blade deviations were

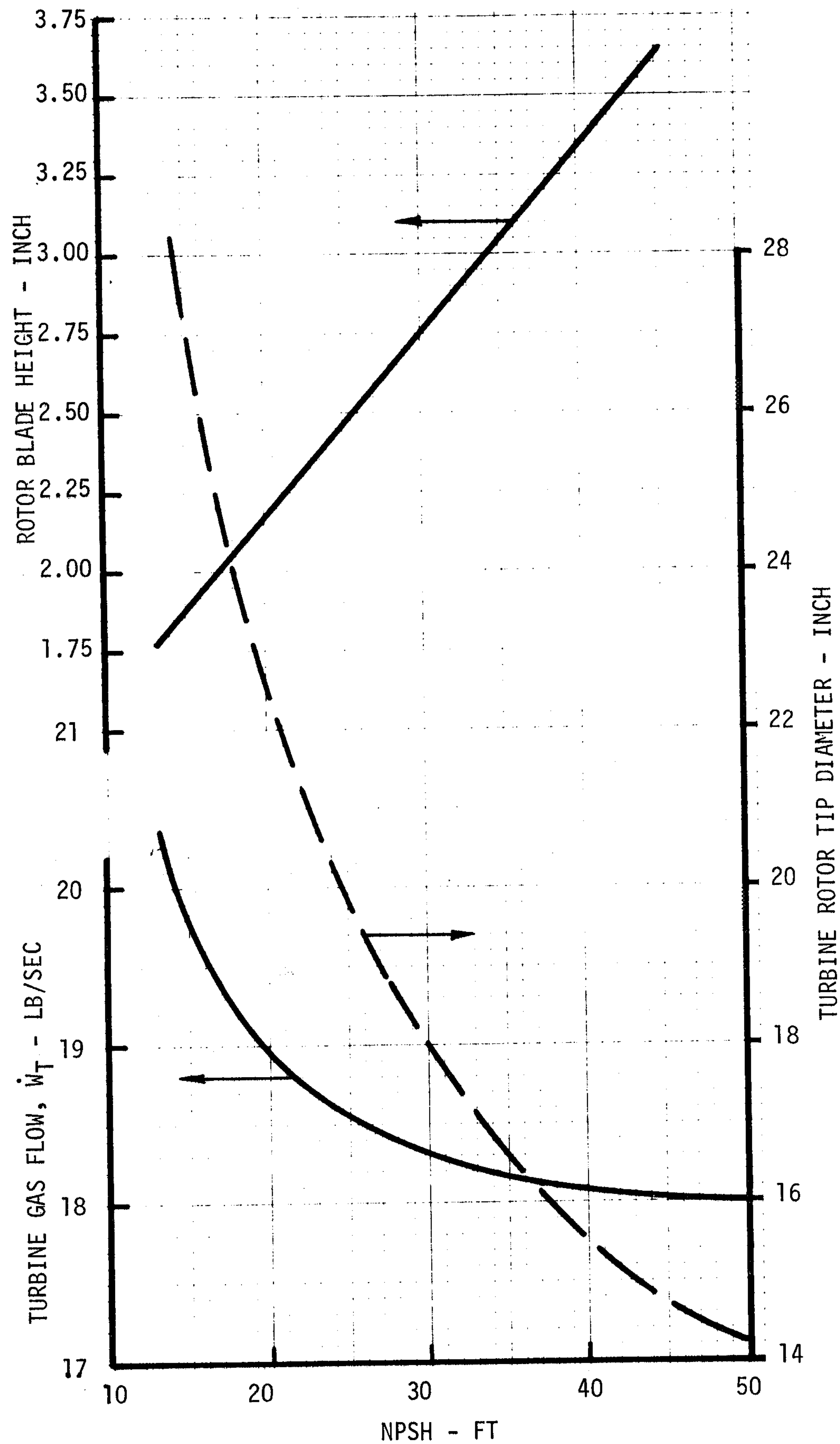


Figure 86. - Tip Diameter, Blade Height, and Flow Rate versus Pump NPSH, LOX Turbine

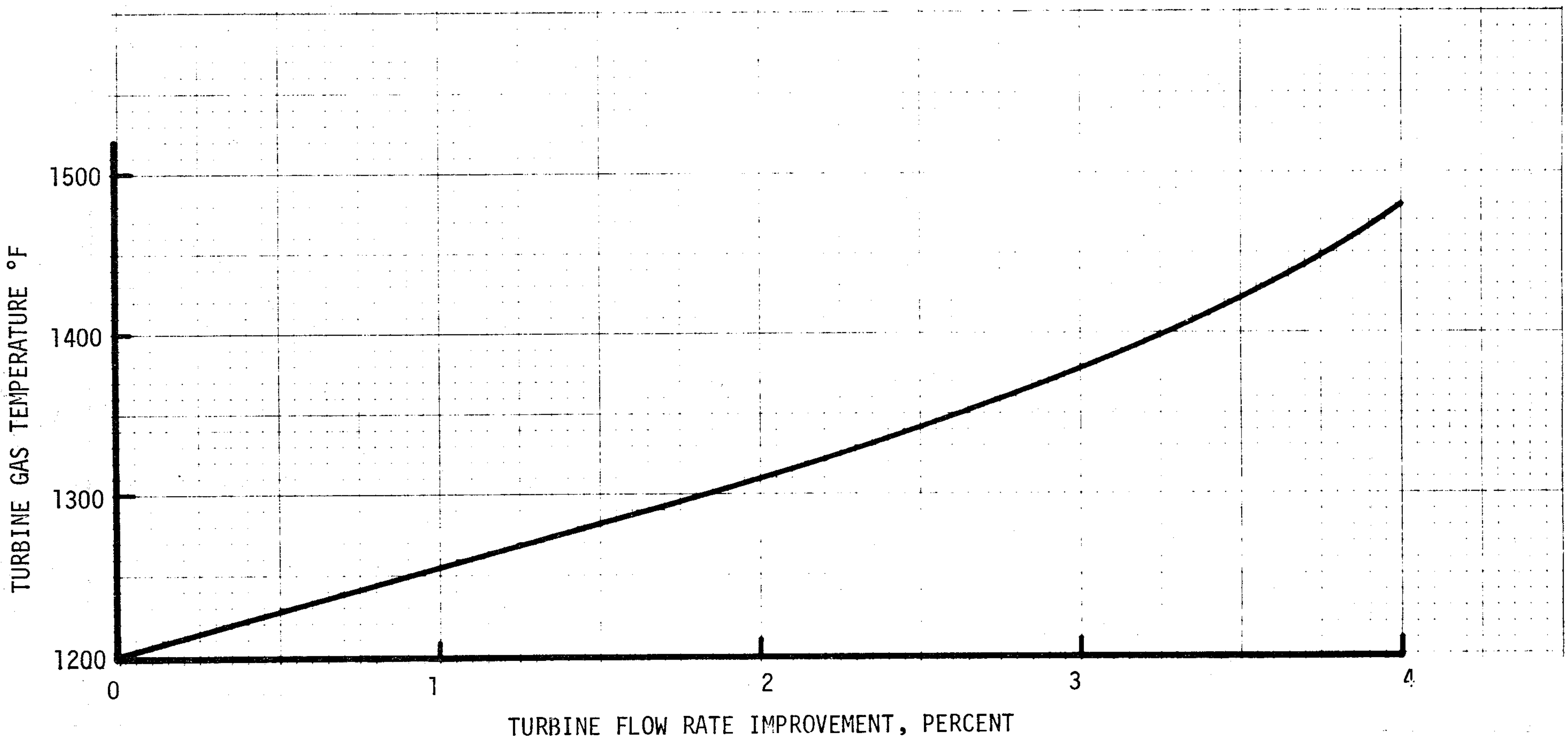


Figure 87. - Effect of Fuel Turbine Gas Temperature upon Turbine Flow Rate

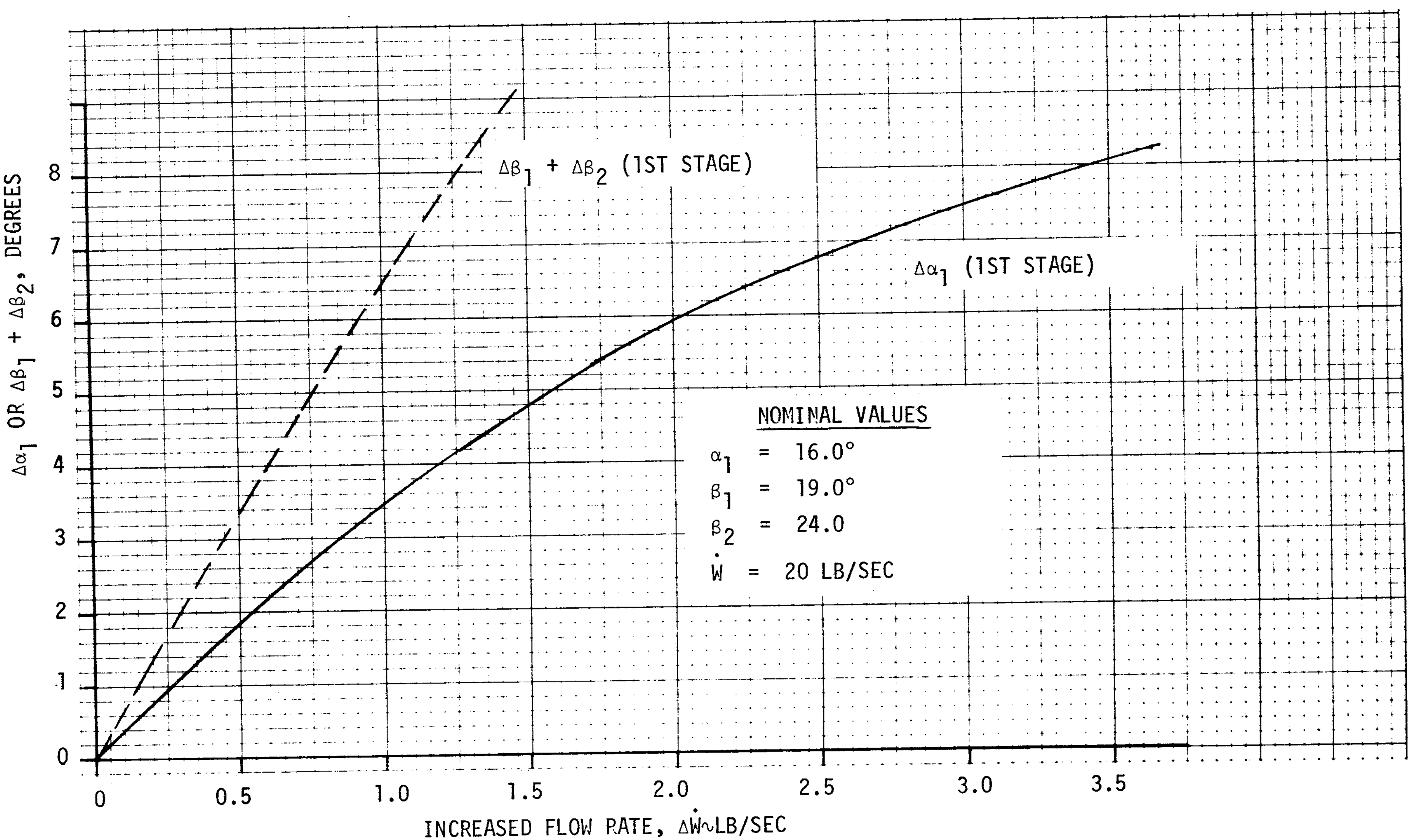


Figure 88. - Effect of First Nozzle Vane Angle Deviation upon Flow Rate, Fuel Turbine

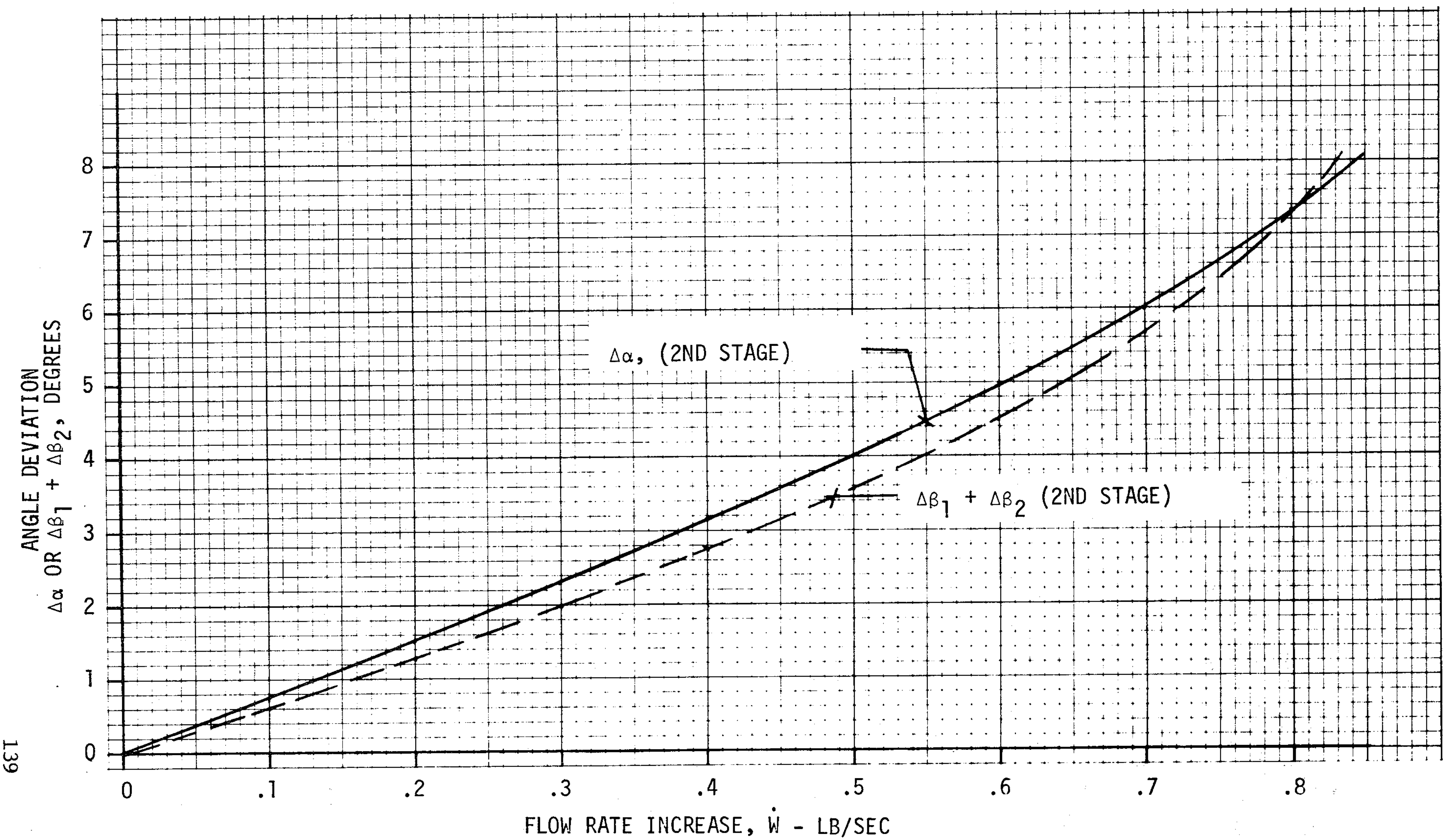


Figure 89. - Effect of Second Nozzle and Second Rotor Angle Deviation upon Flow Rate, Fuel Turbine

combined for each stage and are shown on Figures No. 88 and No. 89 as a function of flow-rate change. The first rotor shows the greatest effect upon flow-rate because of the work-split effect. At 9-degrees inlet and exit angle deviation, the flow-rate increased by 7.5%. The second rotor deviation of 9-degrees would increase flow rate by only 4.2%.

d Flow Passage Surface Finish

The roughness of the flow passages causes friction losses which reduce the available enthalpy of the propellant. Friction loss is determined by using a technique based upon Moody's friction loss formula for pipes. The friction loss then is applied to the velocity head in the flow passages to determine the performance loss. The first-stage nozzle has the most significant loss because of the high velocity. For a surface roughness of 2000 microin., the nozzle loss amounts to an increased propellant flow of 6.5%. Flow-rate as a function of surface finish is shown on Figure No. 90.

Losses in the first-stage rotor and second-stage nozzle and rotor are much less than the first nozzle. The first rotor loss amounts to a 2% flow increase and the second rotor loss is only 0.15%. The surface finish versus flow-rate for these passages is shown on Figure No. 91.

e Rotor Tip Clearances

The effect of rotor blade radial clearance upon turbine performance was evaluated using an empirical method whereby the leakage area to the blade axial flow area is proportioned. The first-stage rotor accounts for 80% of the total turbine power; therefore, the first-stage tip clearance has a predominate effect upon the total leakage losses. The tip clearance effect for plain, unshrouded blades of the base case machine is shown on Figure No. 92.

f Rotational Speed Variation

The turbine design speed variation investigation again was carried out in conjunction with the investigation of pump NPSH effects with a varying inlet diameter. The turbine rotor tip diameters, blade heights, and the propellant flow rates were compared with turbine design speeds corresponding various pump NPSH levels. They are plotted versus the pump NPSH on Figure No. 93.

(c) Turbopumps

The LOX and fuel turbopump designs were evaluated to determine the effect of NPSH upon turbopump weight. The design sketches shown on Figures No. 1, No. 2 and No. 7 through No. 10 were utilized

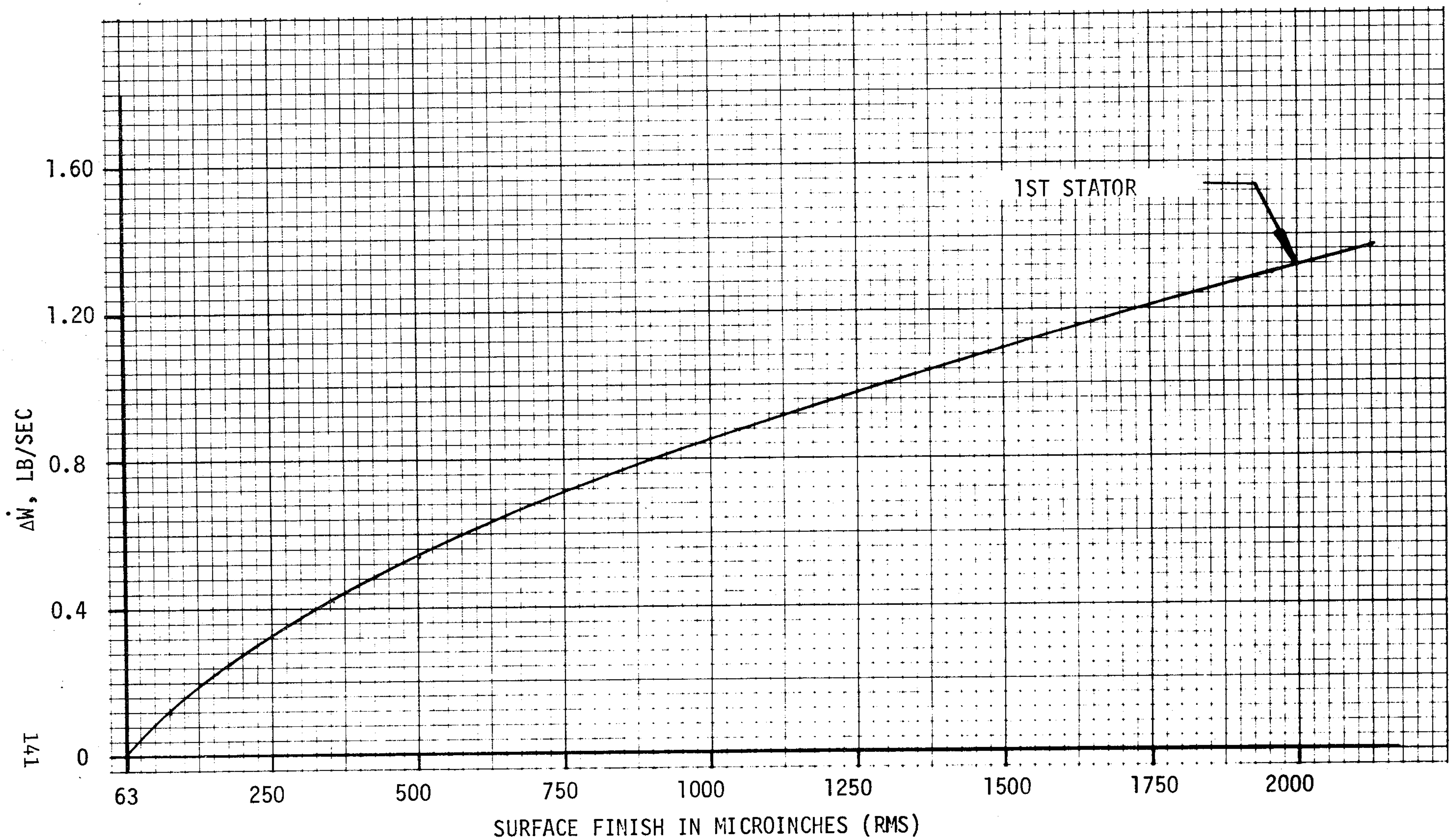


Figure 90. - Effect of First Stator Surface Finish upon Flow Rate, Fuel Turbine

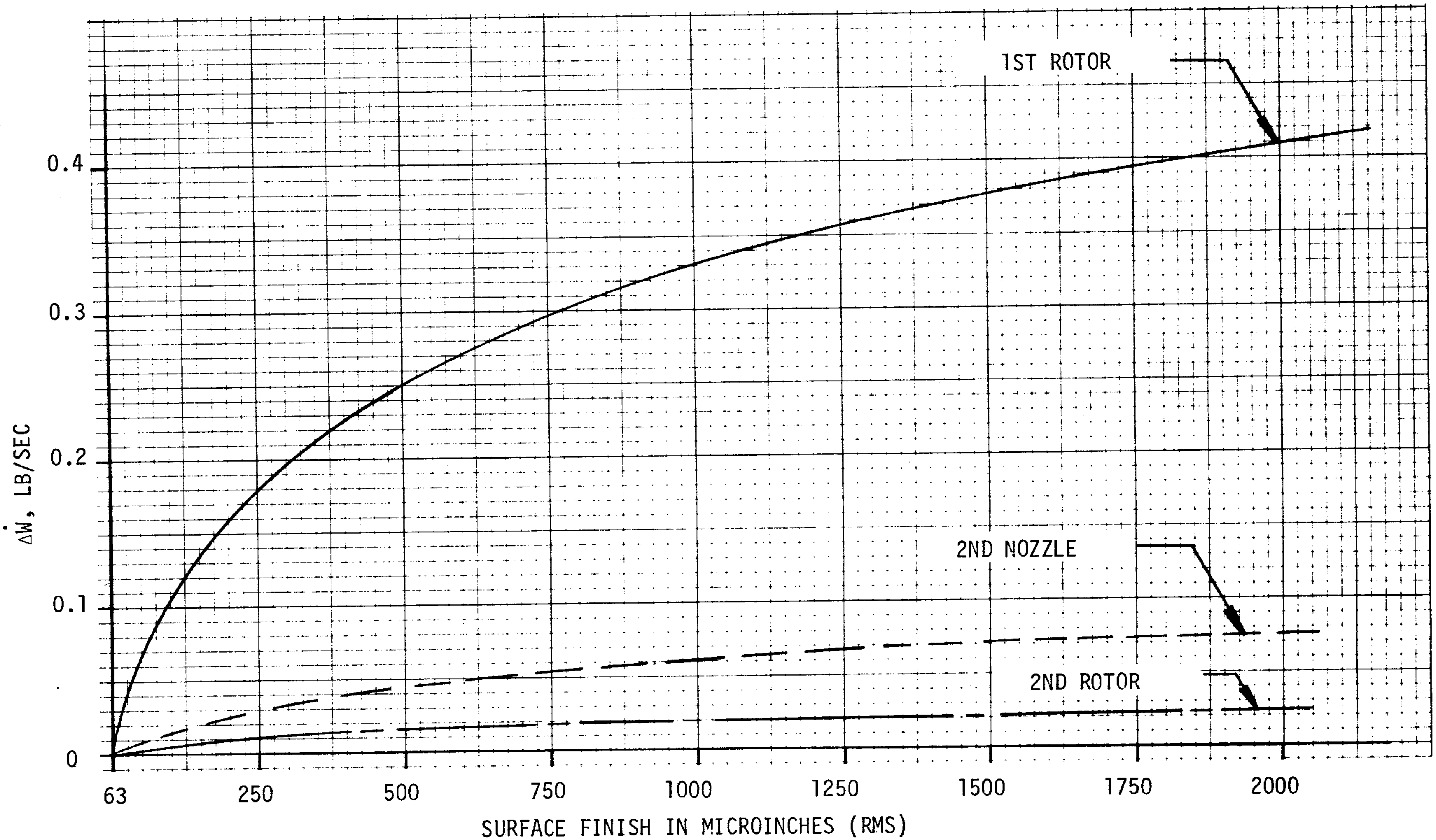


Figure 91. - Effect of Surface Finish upon Flow Rate, Fuel Turbine

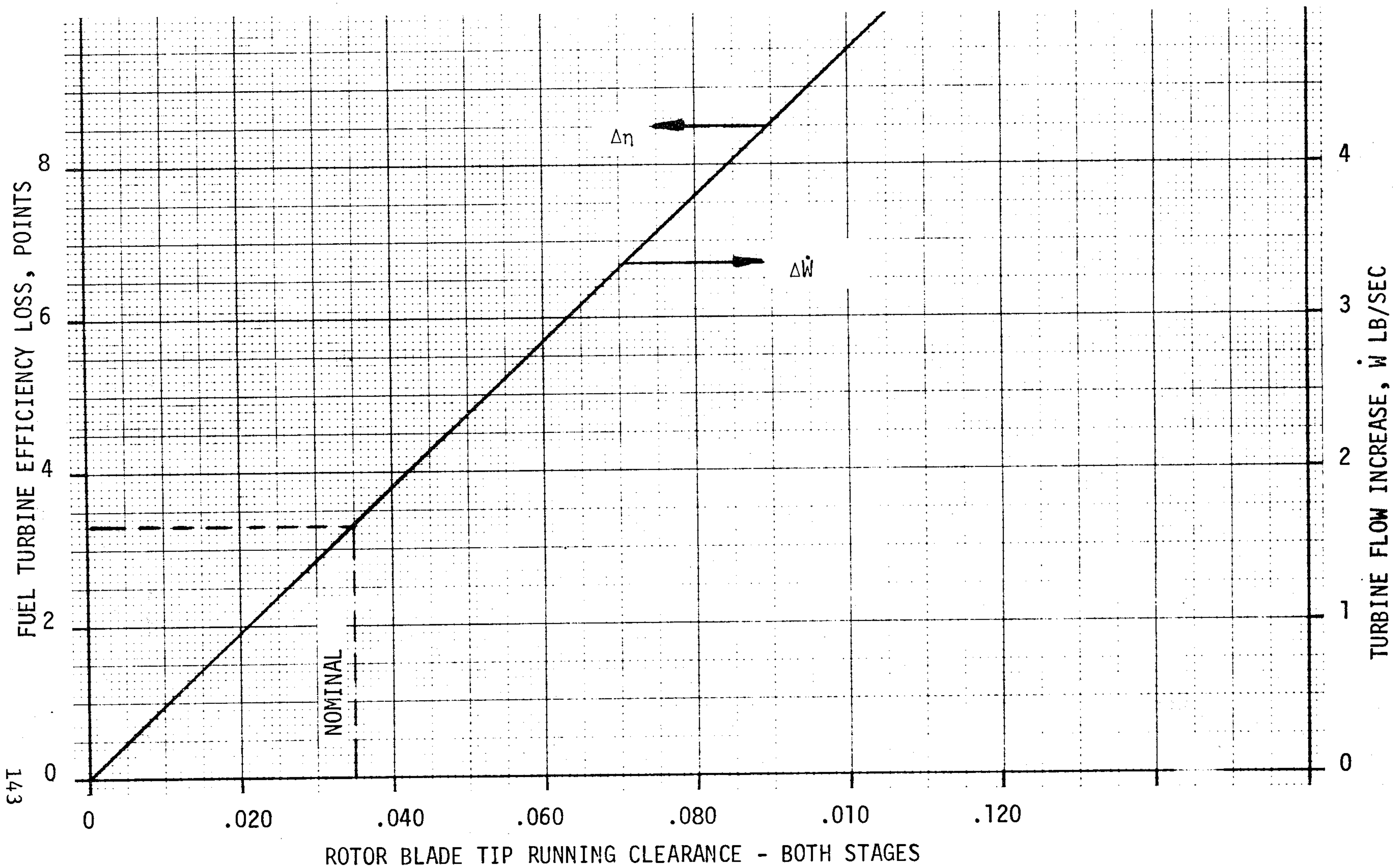


Figure 92. - Combined Effect of Tip Clearance upon Efficiency and Flow Rate, Fuel Turbine

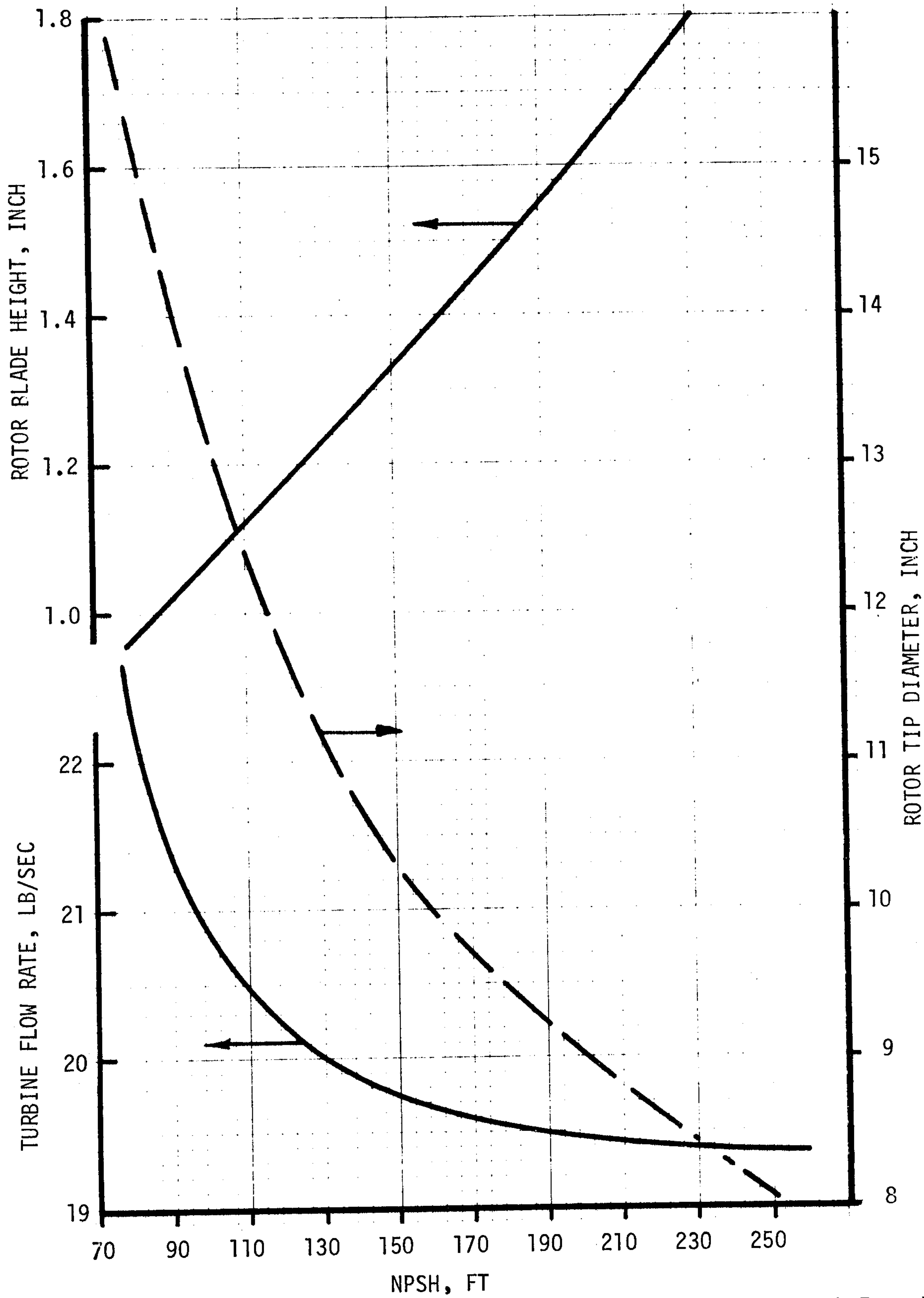


Figure 93. - Variation of Tip Diameter, Blade Height, and Flow Rate with Pump NPSH, Fuel Turbine

in preparing the detailed weight estimated included as Appendix J for three levels of required NPSH for both the LOX and fuel turbopumps. These data are plotted in terms of dry weight versus required NPSH on Figures No. 94 and No. 95.

(3) Component Performance versus Engine Performance

While all of the preceding data can be readily used to relate mechanical design requirements and cost variations to performance in terms of turbine flow rate or bleed ratio, it was still necessary to relate turbine flow rate to engine performance. The following describes the method used to evaluate that relationship and summarizes its results.

The basic engine data used in the study were:

Engine Vacuum Thrust - 300,000 lb

Thrust Chamber Pressure - 1200 psia

Engine Mixture Ratio - 5.0

Nozzle Area Ratio - 50

For series flow turbines with the fuel turbine preceding the oxidizer turbine, the following nominal data were used:

Parameter	Fuel Turbine	Oxidizer Turbine
Inlet Pressure, psia	1190	135
Exit Pressure, psia	152	40
Inlet Temperature, °R	1660	1250
Efficiency, %	53	28
Flow Rate, lb/sec	20	20

In addition to the nominal point investigation, the turbine flow rate was varied arbitrarily to determine the effect upon engine performance. The result of this analysis is depicted on Figure No. 96 which shows that the reduction in engine specific impulse with increasing turbine flow rate is caused by two major factors. Increasing the turbine flow rate causes increases in the thrust chamber mixture ratio which result in reduced theoretical specific impulse. This loss is in addition to the loss associated with dumping a higher percentage of the engine flow inefficiently overboard through a turbine exhaust nozzle.

Fuel turbine inlet temperatures of 1960°F and 2460°R also were investigated. Oxidizer turbine inlet temperatures were calculated assuming a constant fuel turbine pressure ratio. The nominal turbine flow requirement for the increased inlet temperatures was adjusted accordingly for the higher energy drive fluid. Also, the effect of variations in this turbine flow rate upon nominal engine performance was determined. The results of the turbine inlet temperature investigation are shown on Figure No. 97. For fixed

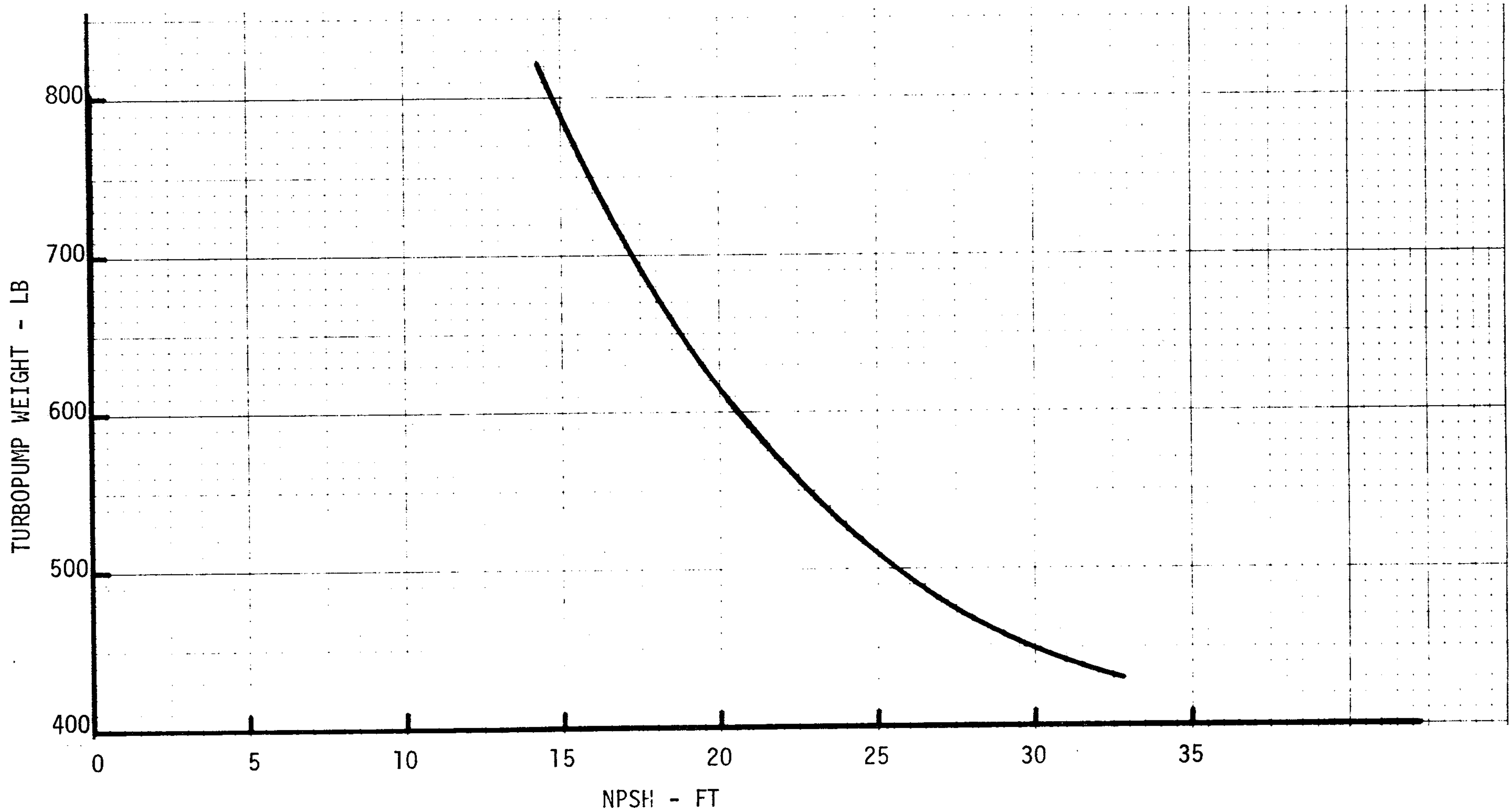


Figure 94. - Weight Effect of NPSH, LOX Turbopump

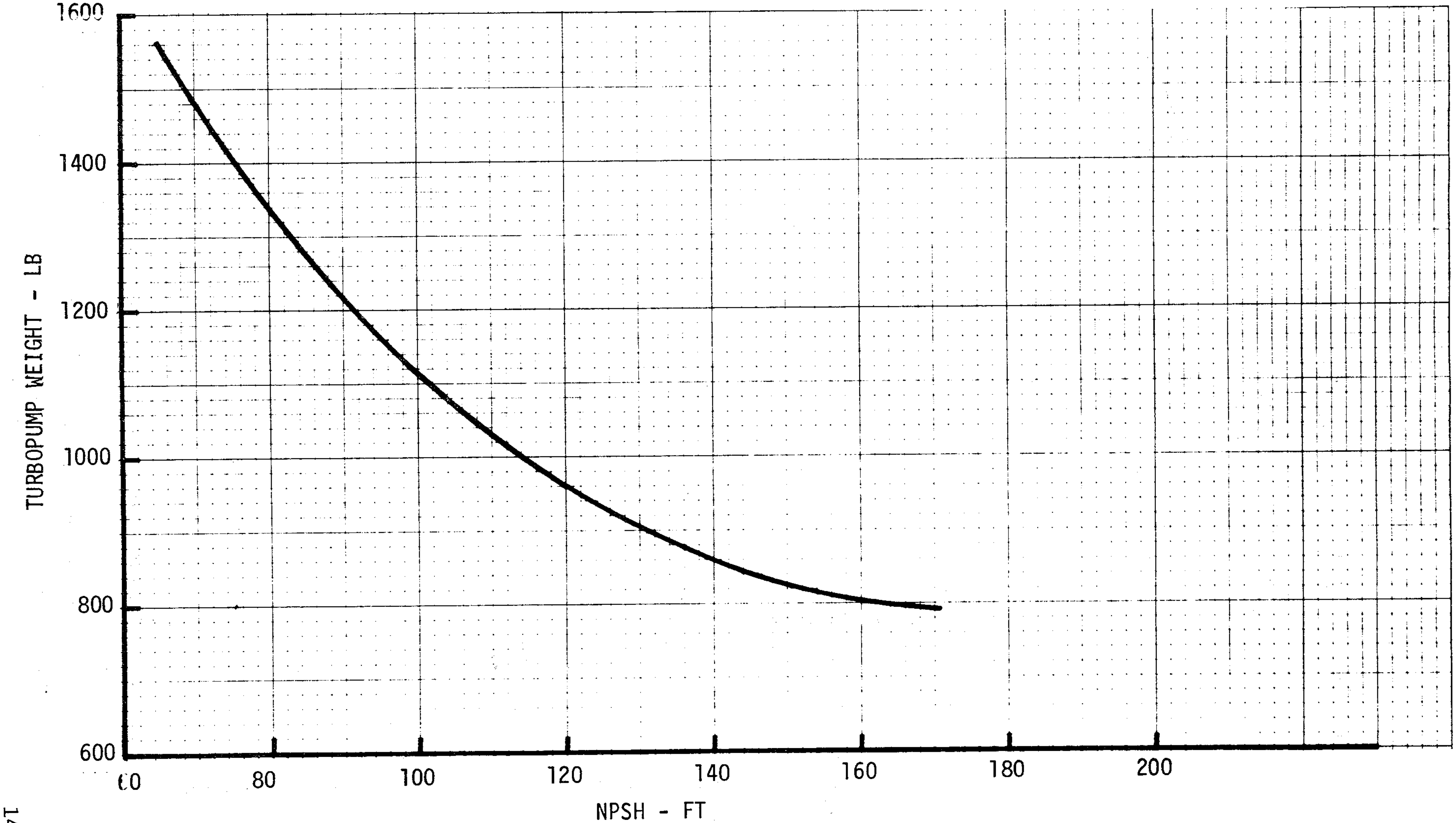


Figure 95. - Weight Effect of NPSH, Fuel Turbopump

NOTES: (1) GAS GENERATOR CYCLE LO_2/LH_2 ENGINE, THRUST CHAMBER PRESSURE = 1200 PSIA, ENGINE MIXTURE RATIO = 5.0, NOZZLE AREA RATIO = 50
(2) 95% OF THEORETICAL THRUST CHAMBER I_S
(3) BASED UPON SERIES FLOW TURBINES, FUEL TURBINE INLET TEMP. = 1660°R, FUEL TURBINE PRESSURE RATIO = 7.83, ΔP LINE FUEL TURBINE EXIT TO OX. TURBINE INLET = 17 PSI, OX. TURBINE PRESSURE RATIO = 3.375, FUEL TURBINE EFFICIENCY = 53%, OX TURBINE EFF. = 28%
(4) THREE SECS LESS THAN I_S NOMINAL DUE TO 3 SIGMA COMPONENT VARIATIONS AND INSTRUMENTATION ACCURACY.

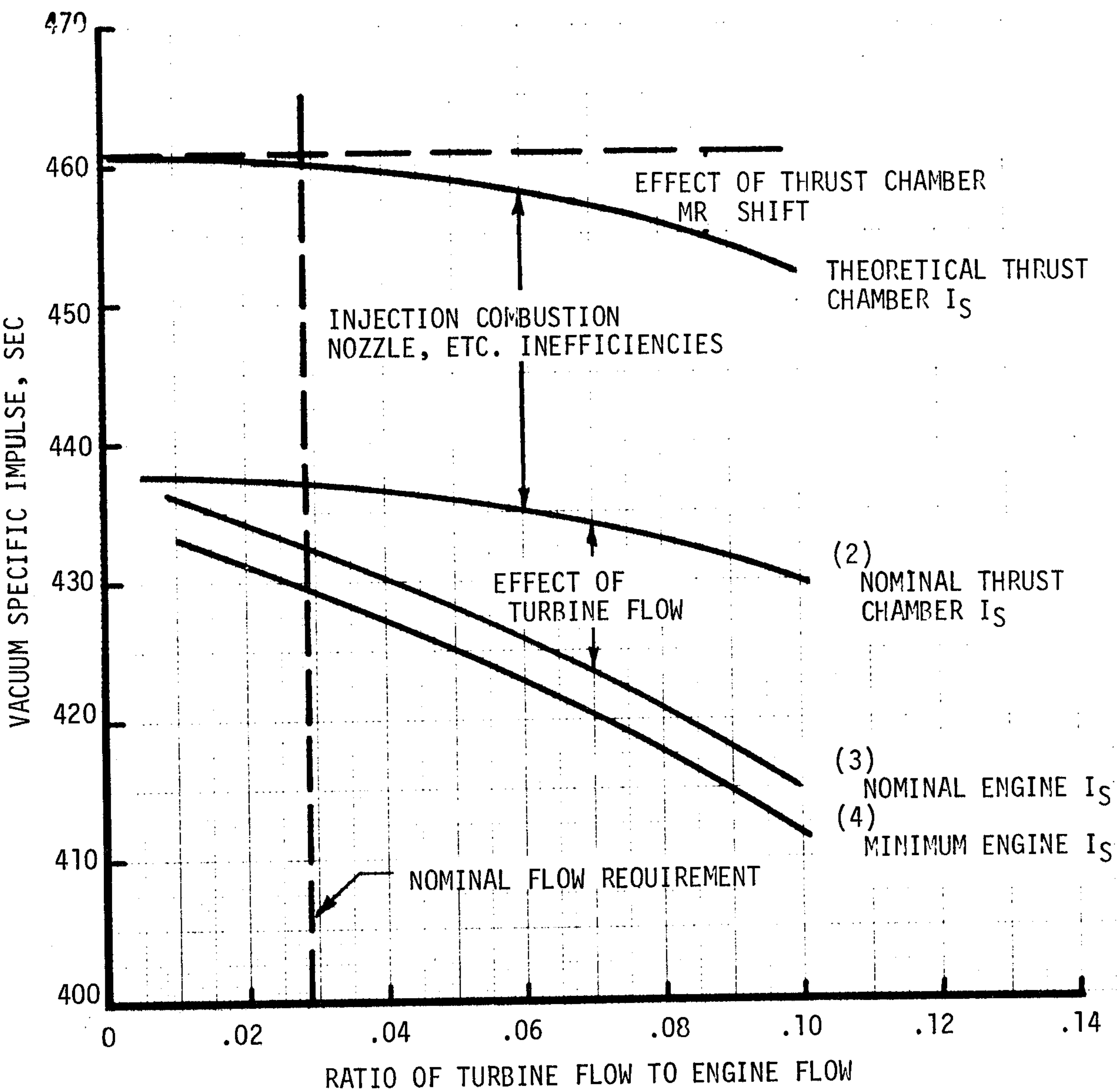


Figure 96. - Vacuum Specific Impulse versus Ratio of Turbine Flow to Engine Flow

NOTES: (1) GAS GENERATOR CYCLE LO_2/LH_2 ENGINE, THRUST CHAMBER PRESSURE = 1200 PSIA ENGINE MIXTURE RATIO = 5.0, NOZZLE AREA RATIO = 50
(2) 95% OF THEORETICAL THRUST CHAMBER I_S ASSUMED
(3) SERIES FLOW TURBINES, FUEL TURBINE PRESSURE RATIO = 7.83, ΔP LINE FUEL TURBINE EXIT TO OX TURBINE INLET = 17 PSI, OX. TURBINE PRESSURE RATIO = 3.375, FUEL TURBINE EFFICIENCY = 53% OX TURBINE EFFICIENCY = 28%

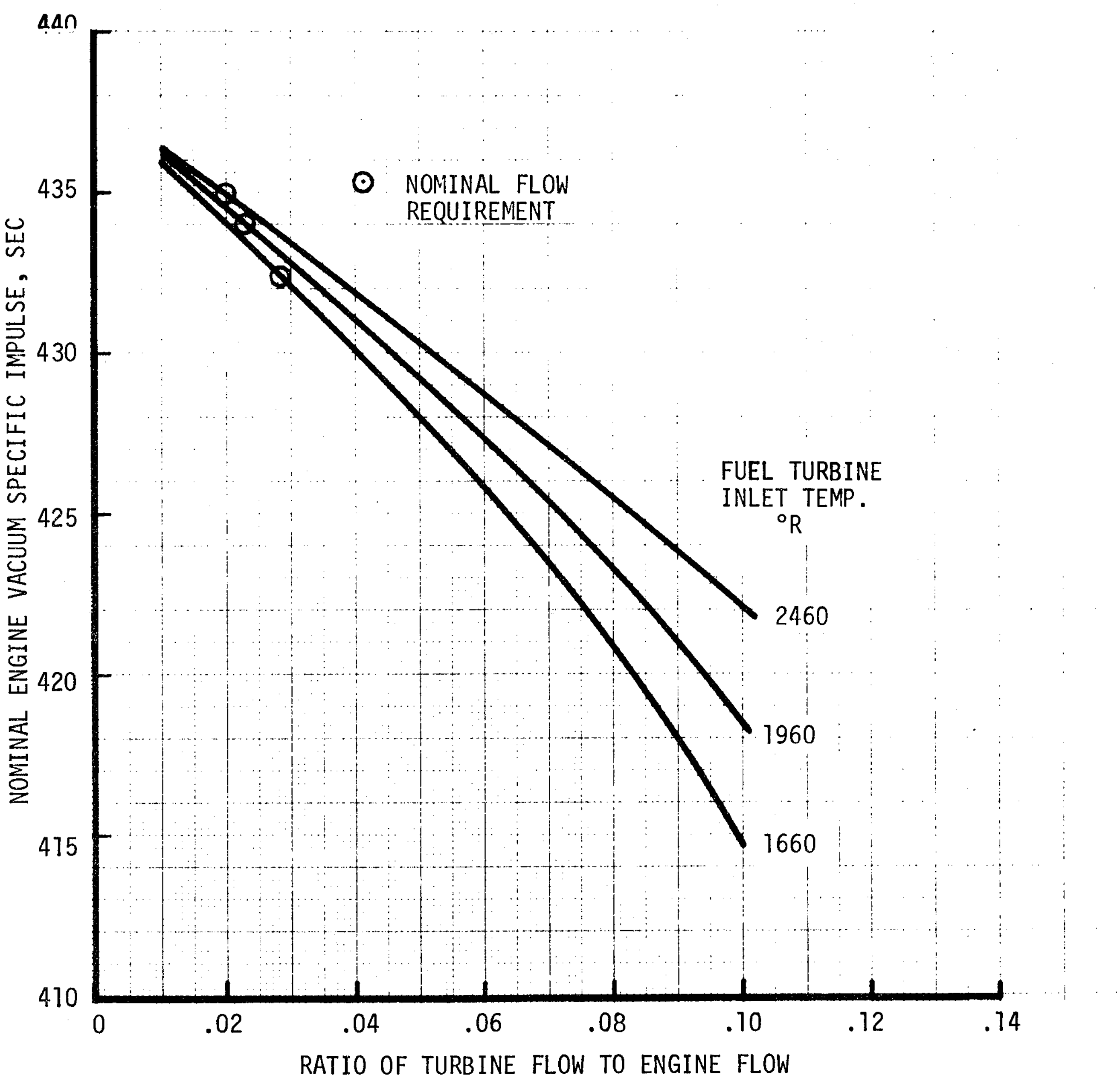


Figure 97. - Nominal Engine Vacuum Specific Impulse versus Ratio of Turbine Flow to Engine Flow for Various Fuel Turbine Inlet Temperatures

pressure ratio turbines with constant efficiencies, increasing the turbine inlet temperature results in reduced turbine weight flow requirements and hence, higher engine specific impulse as shown by the nominal points on Figure No. 97. The higher inlet temperatures also result in higher turbine exhaust temperatures and turbine exhaust specific impulse values which contribute to the increased engine specific impulse.

The data and assumptions used to construct Figures No. 96 and No. 97 are discussed in the paragraphs which follow.

Theoretical shifting equilibrium vacuum specific impulse is shown as a function of mixture ratio on Figure No. 98 for a thrust chamber pressure of 1200 psia and a nozzle area ratio of 50. It was used in conjunction with Figure No. 99 to construct the theoretical thrust chamber specific impulse curve shown on Figure No. 96. Figure No. 99 gives the effect of the thrust chamber flow requirement and gas generator mixture ratio (fuel turbine inlet temperature) upon the thrust chamber mixture ratio and shows that for a given turbine flow requirement, increasing the fuel turbine inlet temperature reduces the thrust chamber mixture ratio shift and hence, performance loss.

The nominal thrust chamber specific impulse shown on Figure No. 96 is based upon 95% of the theoretical value. This percent of theoretical is representative of those obtained with the J-2, RL-10 and the M-1 target values. Based upon the existing data (Refs. 2, 3 and 4), the percentages of theoretical thrust chamber specific impulse for the M-1, J-2, and RL-10 engines were determined to be 95.1%, 95.3%, and 94%, respectively.

To establish the nominal engine performance, it was necessary to determine the turbine exhaust specific impulse values. This data is presented on Figure No. 100 for a turbine exhaust nozzle area ratio of 5. The data points used in the analysis are based upon the turbine efficiency and inlet and exit pressures discussed previously. The following relationship then was used to calculate the nominal engine specific impulse from the nominal thrust chamber and turbine exhaust specific impulses.

$$I_{SP_{VE}} = \frac{W_{TC}}{\dot{W}_E} I_{SP_{V_{TC}}} + \frac{\dot{W}_{gg}}{\dot{W}_E} I_{SP_{V_{TE}}}$$

$I_{SP_{VE}}$ = Nominal engine vacuum specific impulse

$I_{SP_{V_{TE}}}$ = Nominal thrust chamber specific impulse

$I_{SP_{V_{TE}}}$ = Turbine exhaust specific impulse

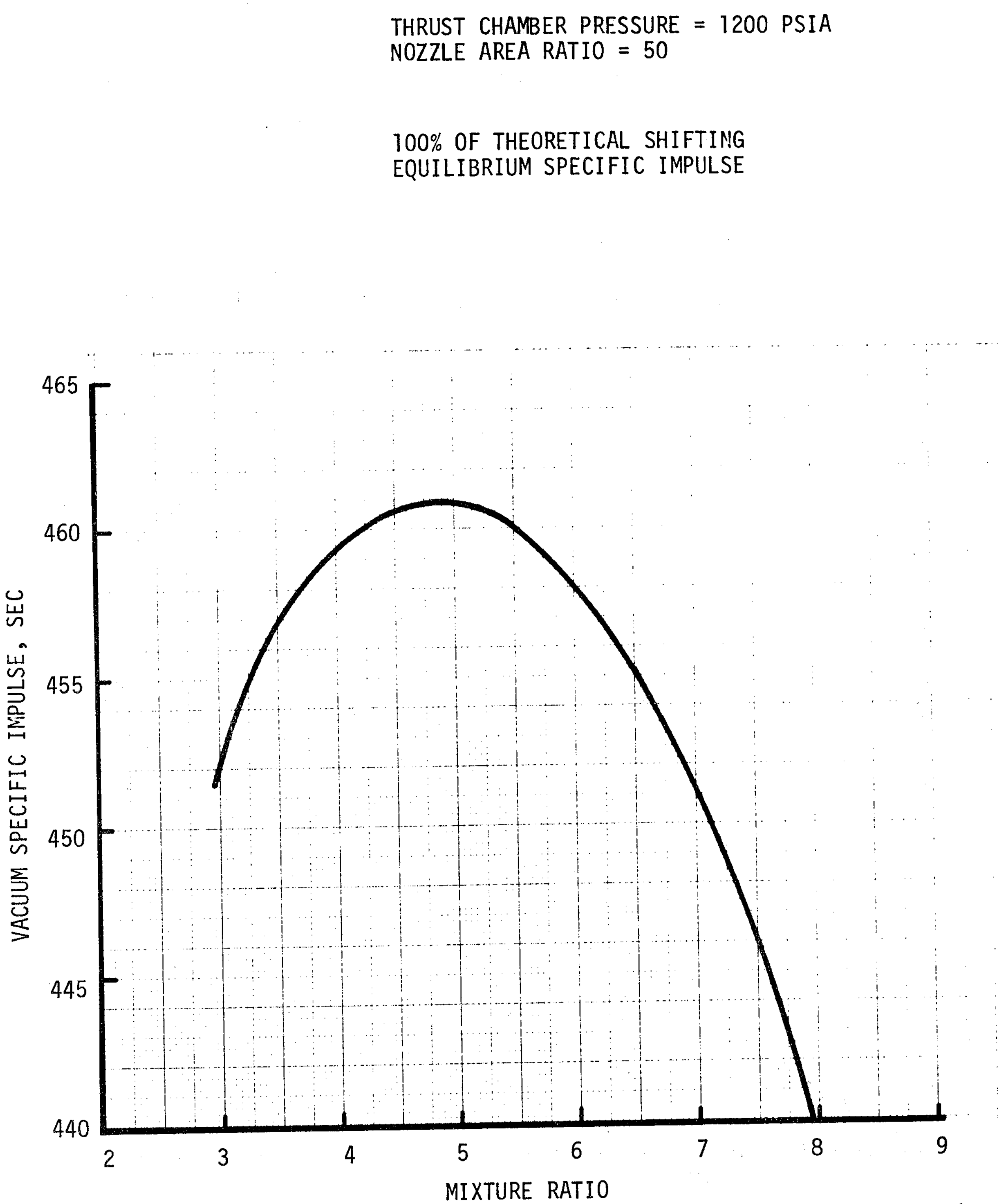


Figure 98. - Theoretical Vacuum Specific Impulse versus Mixture Ratio

$$MR_{TC} = \left(\frac{\dot{W}_{TC}/\dot{W}_E}{\frac{1}{1 + MR_E} - \frac{1}{1 + MR_{GG}} \times \frac{\dot{W}_{gg}}{\dot{W}_E}} \right)$$

MR_{TC} = THRUST CHAMBER MIXTURE RATIO

MR_E = ENGINE MIXTURE RATIO

MR_{GG} = GAS GENERATOR MIXTURE RATIO

$\dot{W}_{TC}$ = THRUST CHAMBER FLOW RATE

W_E = ENGINE FLOW RATE

W_{GG} = GAS GENERATOR FLOW RATE = TURBINE FLOW RATE

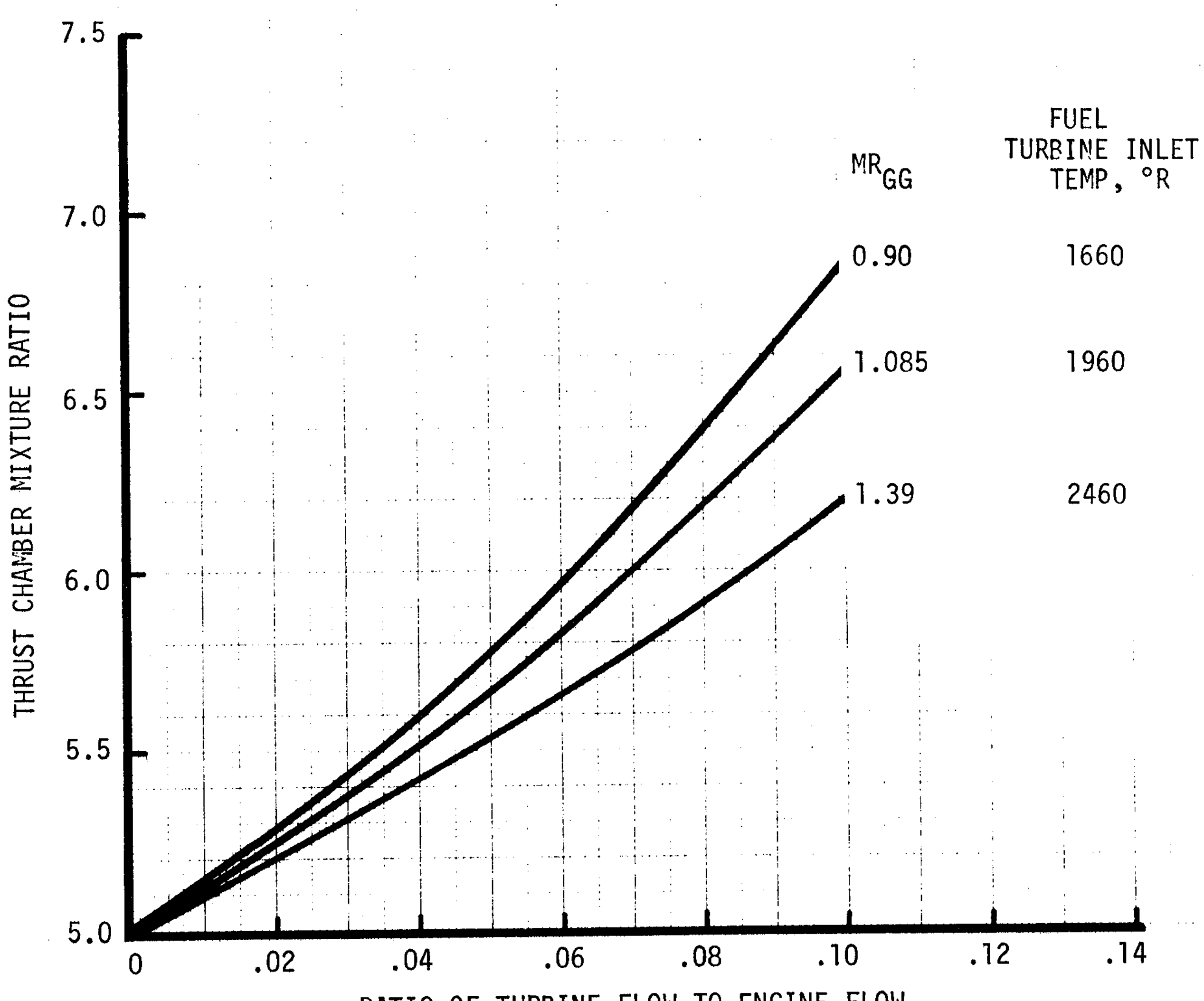


Figure 99. - Thrust Chamber Mixture Ratio versus Turbine Flow Requirement

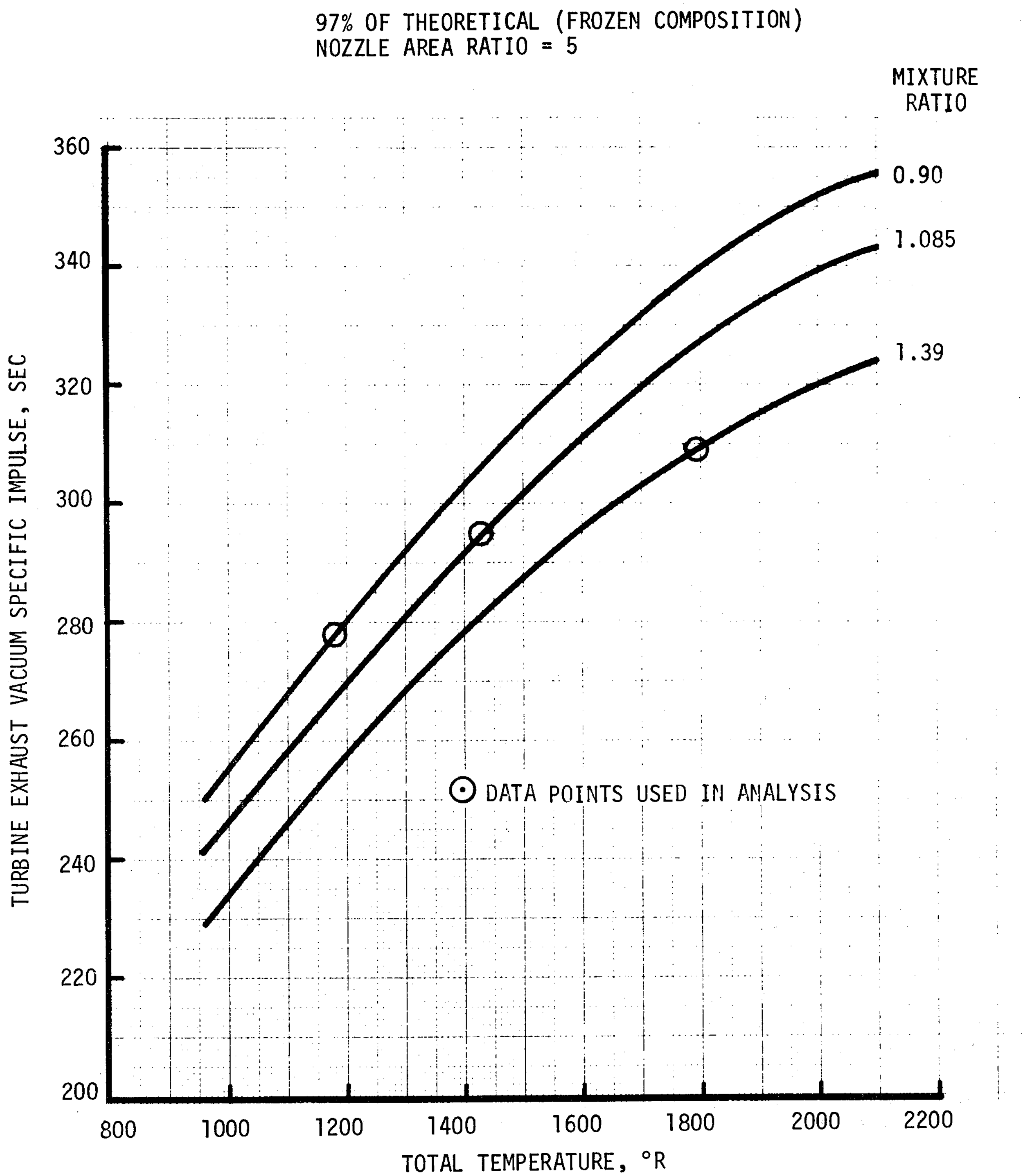


Figure 100. - Turbine Exhaust Vacuum Specific Impulse versus Total Temperature

$\dot{W}_{TC}$ = Thrust chamber flow rate

$\dot{W}_{E}$ = Engine flow rate

$\dot{W}_{gg}$ = Gas generator or turbine flow rate

To obtain the minimum engine vacuum specific impulse shown on Figure No. 96, the nominal was adjusted by three seconds to account for three sigma component variations and instrumentation accuracy. The differences between the nominal and minimum specific impulse values for the M-1, J-2 and RL-10 are 2.0, 4.0 and 5.0 sec per References 2 through 4, respectively.

The above data were utilized in conjunction with turbopump performance calculations to generate the engine specific impulse influence coefficients shown on Table IX. It should be noted that only the turbine flow rate and turbine inlet temperature coefficients are independent partial derivities. Also, the pump and turbine efficiency coefficients are derived from the flow rate coefficient and linearized base case turbopump performance curves.

TABLE IX. - INFLUENCE COEFFICIENTS
ENGINE SPECIFIC IMPULSE

Coefficient	Value
Turbine Flow Rate	0.296 sec/lb/sec
Turbine Inlet Temperature	0.003 sec/°F
Pump Efficiency	0.086 sec/Point
Turbine Efficiency	0.114 sec/Point

(4) Component Performance versus Over-All Cost

The third and final major segment required in developing the cost optimization methodology was the relationship between component performance and over-all costs. The Boeing Company had recently completed a major cost versus performance study (Contract NAS 2-5056) for the referenced MMLV missions and the published data (Ref. 1) were utilized in the Low Cost Turbopump Study because of the applicability of the MMLV mission requirements. However, in any future program wherein the optimization methodology developed herein is used for a different mission, it will be necessary to conduct mission level studies to define the cost versus performance relationships in a manner similar to that shown for the mission considered in this study. While it is recognized that extensive over-all cost studies of this type represent significant expenditures in both time and money, no reasonable alternative to this procedure now exists.

In its simplest form, the data required for the cost optimization methodology consist of the two basic curves shown on

Figures No. 101 and No. 102. These curves were derived from the Boeing data and represent changes in program costs in terms of changes in engine weight or stage mass fraction and engine (trajectory averaged) specific impulse. The most rigorous analysis would call for significantly more data in connection with the stage burnout equation, but for the purposes of illustrating the cost optimization methodology, the linearizations shown on Figures No. 101 and No. 102 are adequate and provide a data accuracy of within 5% over the ranges shown.

In view of the over-all cost versus performance data being derived directly from Reference 1, it is subject to the assumptions and limitations described therein.

b. Fixed Costs

(1) Design

All development and production phase design costs can be considered to be fixed for any particular schedule requirement because of their insensitivity to design requirements at the performance and reliability levels of interest. However, for the purposes of this study, they were considered a variable function of the turbopump qualification schedule.

(2) Fabrication

All fabrication and assembly facilities costs (i.e., machine tools, assembly clean room, part storage, part cleaning, part balancing, and proof test) as well as facilities and maintenance costs are considered to be fixed. They are not included in the data shown in this report, except as they influence applicable overhead rates. Special fabrication tool costs are considered to be variable functions of the requirements, but generally, no variation in cost was noted over the range of requirements investigated.

(3) Test

Test facilities construction costs are considered to be fixed and are not included in this report. Facilities activation costs are variable functions of schedular requirements in that they are dependent upon the number of facilities requiring activation.

4. <u>Synthesis of Design Requirements to Yield Minimum Over-All Costs</u>

The technique used in Task I to quantify the relationship of requirements to turbopump cost parameters, vehicle cost parameters, turbopump cost, vehicle cost, and over-all nonrecurring cost is outlined below:

<u>Step 1</u>: Establish vehicle/engine design requirements "base values (Appendix C).

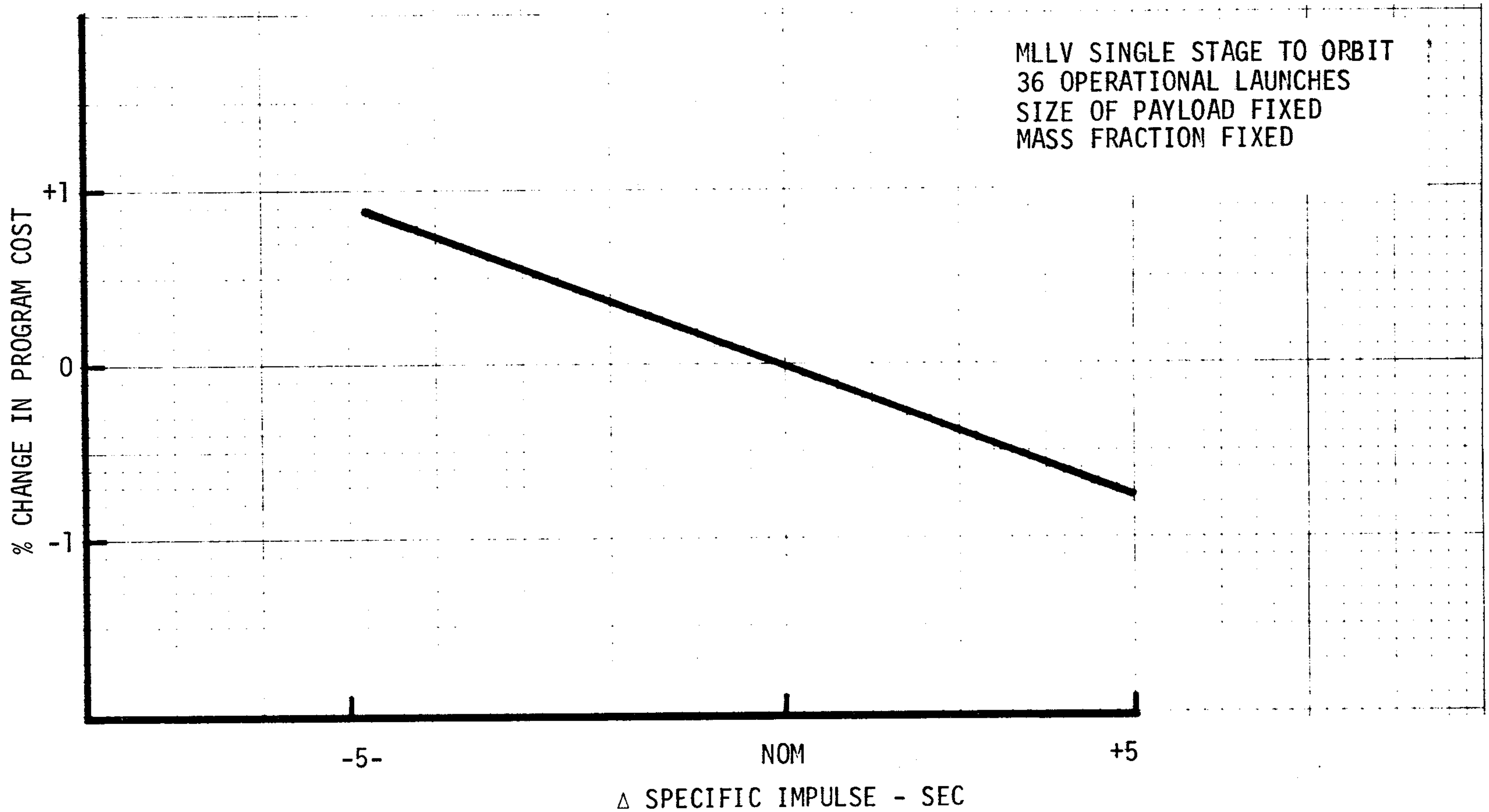


Figure 101. - Sensitivity of Over-All Program Cost to Engine Specific Impulse

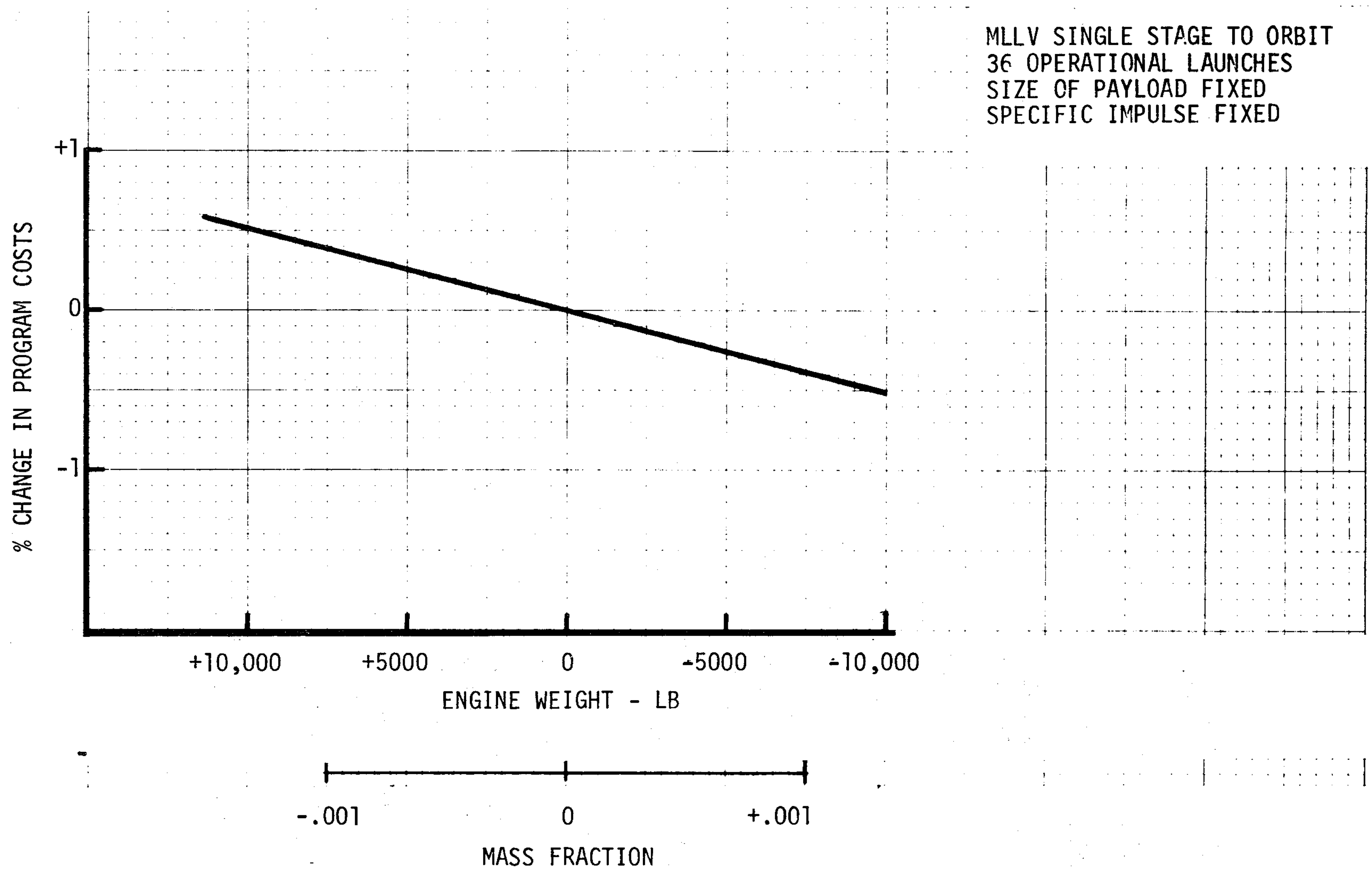


Figure 102. - Sensitivity of Over-All Cost to Engine Weight

Step 2: Select turbopump "base" configuration (Table II and Figures No. 1 and No. 2).

Step 3: Categorize turbopump design requirements (Appendix C).

Step 4: Establish turbopump "base" value design requirements (Appendix C).

Step 5: Establish the variation of turbopump design requirements (Appendix C).

Step 6: Determine turbopump cost parameters (i.e., manhours) as a function of design requirements including all turbopump cost-contributing operations (i.e., part fabrication, assembly, and inspection) (Tables III and IV, Appendices H and I, Figures No. 5, No. 6 and and No. 11 through No. 66).

Step 7: Prepare graphical displays of each major turbopump cost parameter for each turbopump design requirement influencing the cost (Figures No. 5, No. 6 and No. 11 through 66).

Step 8: Determine the linear cost function of cost versus hourly manhours and salary manhours for various turbopump operations activities.

Step 9: Determine turbopump operation cost for each turbopump design requirement by applying the linear cost function to cost parameters (Figures No. 5, No. 6 and No. 11 through No. 66).

Step 10: Prepare graphical displays illustrating the influence of design requirements upon subcomponent and component performance (Figures No. 67 through No. 95).

Step 11: Determine the effect of component performance upon engine performance (Figures No. 96 through No. 100 and Table VI).

Step 12: Define the linear effect of engine weight and performance upon over-all program costs (Figures No. 101 and No. 102).

Step 13: Establish turbopump functional assembly level alternative requirements groups and tabulate cost and performance in terms of engine I_{sp} variation (Table XI and Appendix K).

Step 14: Tabulate over-all cost versus requirements groups (Table X).

Step 15: Select cost optimum requirements group (Table X).

Step 16: Select cost optimum subcomponent requirements from functional assembly level grouping (Appendix L).

Steps 1 through 12 were adequately explained in the previous section devoted to Design Requirements versus Cost Data. However, Steps 13

TABLE X. - TURBOPUMP FUNCTIONAL ALTERNATIVE COST OPTIMIZATION SUMMARY

Turbopump Alternative	Turbopump Unit Cost (Dollars)	Turbopump Performance ($\Delta \dot{W}_T$-lb/sec)	Engine Weight (Δ Pounds/Module)	Engine Performance (Δ I_{sp}-sec)	Δ Stage Mass Fraction (Turbopump Defect)	Program Turbopump Costs (Δ Dollars)	Program Performance Cost Changes (Δ Dollars)	Net Program Cost Changes (Δ Dollars)
Fuel								
Base	54,800	-	-	-	-	-	-	-
Alt No. 1	52,400	+0.8	NC	-	NC	-	-	-
Alt No. 2	50,100	+1.7	NC	-	NC	-	-	-
Alt No. 3	69,500	+2.0	+571	-	See Total	-	-	-
Alt No. 4	52,200	-0.3	-103	-	See Total	-	-	-
Oxidizer								
Base	42,300	-	-	-	-	-	-	-
Alt No. 1	40,500	+0.8*	NC	-	NC	-	-	-
Alt No. 2	39,700	+1.7*	NC	-	NC	-	-	-
Alt No. 3	62,500	+2.0*	+281	-	See Total	-	-	-
Alt No. 4	39,300	-0.3*	-66	-	See Total	-	-	-
Total								
Base	97,100	-	-	-	-	-	-	-
Alt No. 1	92,900	+0.8*	NC	-0.24	0	-6,000,000	+5,500,000	-500,000
Alt No. 2	89,800	+1.7*	NC	-0.51	0	-10,000,000	+11,000,000	+1,000,000
Alt No. 3	132,000	+2.0*	+852	-0.60	-0.0032	+49,000,000	+13,200,000	+62,200,000
Alt No. 4	91,500	-0.3*	-167	+0.10	+0.0007	-8,000,000	-2,200,000	-12,200,000

*Fuel Turbopump Controls

through 16 require additional clarification, which is provided in the ensuing discussion.

In some unique instances, individual subcomponent mechanical design requirements can be modified independently to obtain sensible changes in both cost and performance variations. However, in most cases, the subcomponent interaction effects are of a nature that an arbitrary requirement variation in a single component results in a performance change is strongly additive in a complex manner to a similar variation resulting from some other component requirement change. Rotor/impeller outside diameter and concentricity tolerance variations as well as the housing inside diameter and concentricity tolerance variations are particularly sensitive to the interaction effects. As a simple example, if the fuel turbine rotor outside diameter tolerance is varied from ± 0.001 to ± 0.005, the nominal rotor tip clearance must increase by 0.002 with a resultant turbine flow rate increase of approximately 1/2%. A like variation in the nozzle shroud inside diameter tolerance will have a similar directly additive effect while a backplate/bearing housing concentricity allowance increase of 0.004 causes a performance degradation effect that adds at double the indicated rate because the nominal rotor tip clearance must be increased directly with the concentricity allowance.

In view of the interaction sensitivities indicated above, it was necessary to devise an optimization method which would combine the requirement alternatives in such a way that would assure all performance variations are properly accounted for. The most reasonable and attractive method that appears to exist is the consistent, albeit arbitrary, selection of mechanical subcomponent requirements followed by a tabulation of performance and cost for all parts of the turbopump. The selection of arbitrary requirements largely rests upon the application of engineering judgement to assure that reasonable turbopump level combinations result.

The turbopump functional level alternatives shown in Appendix K were prepared utilizing the above basis. Resultant subcomponent requirements were kept at maximum consistency as regards the degree of refinement throughout the turbopumps. Although only four alternatives are shown, any number of combinations could have been defined. The alternatives designated as No. 1 and No. 2 in Appendix K are for the base case level NPSH/size requirement. The separately shown alternatives No. 3 and No. 4 are for variations in NPSH with all other requirements being held constant at the base case values. The optimization process summarized in Appendix K was performed as follows:

Step 1: Utilizing the alternative part level mechanical requirements from Appendix K and the performance effects figures, turbopump level performance is calculated in terms of turbine flow rate increase (or decrease) and/or turbopump weight increase from the base. Care must be taken to assure that all interaction effects are considered.

Step 2: Turbopump level performance changes are converted to engine/stage performance changes in terms of specific impulse and/or mass fraction changes using the influence coefficients of Table IX.

Step 3: Utilizing the alternative part level mechanical requirements from Appendix K and the cost effect figures in context with Tables III and IV and Appendix H, part and turbopump unit cost is calculated. The unit costs can be developed in terms of manhours or prime dollars so as to be independent of overhead structure, but for the examples shown, a sample overhead rate was applied.

Step 4: Using the turbopump unit costs, the program plan (in terms of the number of units), and the appropriate fixed costs, the program turbopump costs are determined in terms of decreases (or increases) in cost to the program for all of the turbopump related operations.

Step 5: Using the performance changes calculated in Step 2 and the over-all program cost sensitivity to performance curves (Figures No. 101 and No. 102), program performance cost changes are calculated in terms of increases (or decreases) in cost to the program for all operations.

Step 6: The results of Steps 4 and 5 are added to obtain the total program cost changes as a function of turbopump functional alternatives. The assumptions used in developing the engine performance influence coefficients prevent valid mixed alternatives such as the "Fuel Base" and "Oxidizer Alternative No. 2" because the power balance changes in such a manner that turbine flow rate control switches from fuel to oxidizer turbopumps. Direct combinations of the NPSH requirement alternatives (No. 3 or No. 4) with either alternative No. 1 or No. 2 are valid and were utilized, although not shown, in selecting the optimal requirements and criteria shown in Appendix L.

Step 7: The optimum alternative is selected and the resulting design requirements and criteria are tabulated as shown in Appendix L.

B. TASK II - EXAMINATION OF COST-CONTRIBUTING OPERATIONS

Task II was divided into the following four subtasks:

IIa - Examination of technological level of cost-contributing operations

IIb - Examination of the types of operations

IIc - Selection of the most significant operations in terms of program costs and evaluating alternative operations

IId - Selection of operations for technology development

Subtasks IIa, IIb, and IIc were conducted in conjunction with Subtasks Ia and Ic, thereby forming an integral part of those studies. The methodology applied to obtain the results achieved was fully described in Section III,A of this report. However, the results of these subtask efforts are summarized on Table XI, which provides a clear picture of what cost-contributing operations categories are responsible for the major turbopump costs. As would be expected in any high production program, the production phase fabrication and turbopump level test operations costs completely overshadow all others. In research and development type programs with relatively few launches or vehicles with a minimal number of engine modules, increased importance is placed upon the development phase operations.

Consequently, the Task II effort was directed toward investigating alternative fabrication and test technological levels as well as types that would be applicable to either development or production phase operations.

As explained earlier in the Task I discussion, little reduction in fabrication costs is available from changes in the technological level because "commercial" technology either is not able to sustain even the minimum requirements postulated or the "commercial" costs are identical to the "aerospace" costs. However, the types of operations offer significant potential for fabrication cost savings as discussed in Section III,A. The technology needed to obtain these savings currently is available and should be utilized in future programs.

The investigators were unable to define alternative test operations technologies which would permit turbopump calibration to satisfy engine balance requirements. This resulted largely because of the extensive facilities required merely to operate a large turbopump. If engine balance requirements can be relaxed sufficiently or if the turbopump performance variations from unit to unit can be minimized, the type of testing can be changed from hot firings to either air flow tests or even be completely eliminated.

Thus, the sole result of the Task IId effort is the recommendation that the possibility of eliminating the turbopump calibration/acceptance tests be eliminated, especially for production phase operations. A technology program for accomplishing this is outlined in Section IV of this report.

TABLE XI. - TECHNOLOGICAL LEVEL AND SIGNIFICANCE OF COST-CONTRIBUTING OPERATIONS

Operations	Technological Level		Type		Significance (% Turbopump Program Cost)	Requires Technology Development
	Base	Alternative	Base	Alternative		
DEVELOPMENT PHASE						
DESIGN OPERATIONS						
1. Analysis	Aerospace	None	Manual and Computerized	Manual Only	1.23	No
a. Hydraulic/Aerodynamic Performance						
b. Hydraulic/Aerodynamic Loads						
c. Thermal Conditions						
2. Mechanical Design						
a. Critical Speed Determination	Aerospace	None	Manual and Computerized	Manual Only		
b. Structural Analysis						
(1) Static Stress/Deflection Analysis						
(2) Inertia Stress/Deflection Analysis						
(3) Dynamic Stress/Deflection Analysis						
(4) Thermal Stress/Deflection Analysis						
c. Drafting						
(1) Layouts						
(2) Part Fabrication Drawings						
(3) Assembly Processing Drawings						
d. Checking						
3. Fabrication Follow-Up	Aerospace	None	Manual and Computerized	Manual Only		
4. Test Planning and Follow-Up	Aerospace	None	Manual	None		

TABLE XI. - TECHNOLOGICAL LEVEL AND SIGNIFICANCE OF COST-CONTRIBUTING OPERATIONS (cont.)

Operations	Technological Level		Type		Significance (% Turbopump Program Cost)	Requires Technology Development
	Base	Alternative	Base	Alternative		
DEVELOPMENT FABRICATION OPERATIONS	Aerospace	Commercial			0.58	Yes Selected Part Operations
1. Advance Vendor Quotes/Consulting						
2. Procurement Processing/Planning						
3. Tooling Fabrication						
4. Rawstock Procurement						
5. Casting or Forging	See Detailed Part by Part Discussion in Section III,A, Appendices H and I, and Figures No. 11 through No. 62.					
6. Machining						
7. Welding						
8. Subassembly						
9. Assembly						
10. Inspection						
11. Shipping						
DEVELOPMENT TEST OPERATIONS						
1. Subcomponent Test (Part or Feature Level)					0.25	No
a. Subcomponent Proof Tests						
(1) Rotor Proof Tests	Aerospace	None	Spin Tests	Eliminate		
(2) Housing Proof Tests	Aerospace	Commercial	Pressure Tests	Eliminate		
b. Subcomponent Integrity Evaluation						
(1) Vibration Characteristics Definition	Aerospace	Commercial	Vibration Tests	Eliminate		No
(2) Housing Burst Pressure	Aerospace	Commercial	Pressure Tests	Eliminate		
(3) Rotor Burst Speed	Aerospace	Commercial	Spin Tests	Eliminate		
(4) Bearing Life Tests	Aerospace	Commercial	Rotating-Loaded	None		No

TABLE XI. - TECHNOLOGICAL LEVEL AND SIGNIFICANCE OF COST-CONTRIBUTING OPERATIONS (cont.)

Operations	Technological Level		Type		Significance (% Turbopump Program Cost)	Requires Technology Development
	Base	Alternative	Base	Alternative		
DEVELOPMENT TEST OPERATIONS (cont.)						
2. Component Tests (Subassembly Level)					0.28	No
a. Pump Performance Evaluation	Aerospace	Commercial	Simulant Pumping Tests	Eliminate		
b. Power Transmission Performance Evaluation	Aerospace	Commercial	Rotating Propellant	Eliminate		
c. Turbine Performance Evaluation	Aerospace	Commercial	Dynamometer	Eliminate		
3. Turbopump Development Tests					1.95	No
a. Performance Evaluation	Aerospace	None	Hot Firings	None		
b. Life/Reliability Evaluation	Aerospace	None	Hot Firings	None		
c. Malfunction Survival Evaluation	Aerospace	None	Hot Firings	None		
4. Turbopump Acceptance Tests (For R&D Engines)	Aerospace	Commercial	Hot Firings	Eliminate	0.32	Yes
PRODUCTION PHASE						
DESIGN OPERATIONS					0.74	No
1. Performance Modifications	Aerospace	None	Not Applicable	Not Applicable		
2. Mechanical Modifications	Aerospace	None	Not Applicable	Not Applicable		
PRODUCTION FABRICATION OPERATIONS	Aerospace	Commercial			42.4	Yes Selected Part Operations
1. Procurement Processing/Planning						
2. Tooling Fabrication						
3. Rawstock Procurement						
4. Casting or Forging	See Detailed Part by Part Discussion in Section III,A, Appendices H and I, and Figures No. 11 through No. 62.					
5. Machining						
6. Welding						
7. Subassembly						
8. Assembly						
9. Final Assembly (Engine)						

TABLE XI. - TECHNOLOGICAL LEVEL AND SIGNIFICANCE OF COST-CONTRIBUTING OPERATIONS (cont.)

Operations	Technological Level		Type		Significance (% Turbopump Program Cost)	Requires Technology Development
	Base	Alternative	Base	Alternative		
PRODUCTION FABRICATION OPERATIONS (cont.)						
10. Inspection						
11. Storage						
12. Shipping						
PRODUCTION TEST OPERATIONS					39.50	
1. Subcomponent Level Tests					0.12	
a. Rotor Proof Tests	Aerospace	None	Spin Tests	Eliminate		
b. Housing Proof Tests	Aerospace	Commercial	Pressure Tests	Eliminate		
2. Component Level Tests						
a. Pump Calibration	None	Aerospace	None	Analytical	0.0	Yes
b. Turbine Calibration	None	Aerospace	None	Analytical		
3. Turbopump Level Tests					39.50	Yes
a. Acceptance Tests	Aerospace	None	Hot Firing	Eliminate		
b. Post-Test Checkout and Inspections	Aerospace	None	Leak and Torque Checks	Eliminate		
4. Engine Level Tests					Excluded	-
a. Engine Acceptance Tests	Aerospace	None	Hot Firing	None		
b. Post-Test Checkout and Inspections	Aerospace	None	Leak and Torque Checks	None		
5. Stage Level Tests					Excluded	-
a. Flight Readiness Tests	Aerospace	None	Leak and Torque Checks	None		
b. Post-Test Checkout and Inspections	Aerospace	None	Leak and Torque Checks	None		

TABLE XI. - TECHNOLOGICAL LEVEL AND SIGNIFICANCE OF COST-CONTRIBUTING OPERATIONS (cont.)

Operations	Technological Level		Type		Significance (% Turbopump Program Cost)	Requires Technology Development
	Base	Alternative	Base	Alternative		
FIELD MAINTENANCE AND REPAIR OPERATIONS					1,235	No
1. Seal Checks	Aerospace	None	Pressure Test	Eliminate		
2. Seal Replacement (Interfaces)	Aerospace	None	Manual	Eliminate		
3. Torque Checks	Aerospace	None	Manual	Eliminate		
4. Removal and Replacement	Aerospace	None	Manual	None		

C. TASK III - CONCEPTUAL DESIGN

1. Turbopump Pre-Design and Mission, Vehicle, and Engine Trade-Offs

The mission, vehicle, and engine trade-off studies, together with the detailed subcomponent analyses and optimizations form integral parts of the conceptual design. A half-size version of an Advanced Multipurpose Large Launch Vehicle (AMLLV) with a payload capability to low earth orbit of 500,000 lb was selected as a representative reference design case to serve as the basis for optimization. This resulted in the following definition of design characteristics:

Symbol	Characteristic	Value	
		Fuel Turbopump	LOX Turbopump
ΔP	Pump Pressure Rise	1900 psi	1700 psi
$\dot{w}_p$	Pump Flow Rate	125 lb/sec	585 lb/sec
P_{Ti}	Turbine Inlet Pressure	1190 psia	135 psia
T_{TT}	Turbine Inlet Temperature	1660°R	1250°R

Qualitative consideration of the mission/vehicle interactions revealed a strong dependency upon aerodynamic and hydraulic performance of both the turbine and pump. The weight and length of the turbopump became somewhat secondary effects. It was found that the basic, separate turbopump configurations which best served as a basis for generating performance characteristics and investigating mechanical design constraints while offering a reasonable compromise between performance and weight effects incorporated overhung centrifugal pumps. The fuel pump would be driven by a two-row, Curtis, staged, overhung turbine operating in series with a single-stage oxidizer impulse turbine.

The conceptual designs of machines of this type were completed in sufficient depth to demonstrate the cost optimization methodology. Additionally, supporting optimization studies were completed which served to either confirm the basic configuration tentatively selected or permitted modification of the initial configuration to evolve an optimum turbopump for the reference engine.

a. Results

The above indicated performance requirements were utilized along with the Task I results in a brief optimization study to evolve the final selection of the basic turbopump configurations shown on Figures No. 1 and No. 2. Conceptual design was limited to selecting the design requirements and predicting the performance shown in Appendix L and on Table XII.

TABLE XII. - LOST OPTIMUM TURBOPUMP PERFORMANCE SUMMARY

Parameter	Value	
	Fuel	Oxidizer
Shaft Speed (rpm)	30,000	8,000
Pump Flow Rate (lb/sec)	125	585
Pump Pressure Rise (psi)	1900	1700
Pump Efficiency (%)	69.4	69.5
Turbine Pressure Ratio	7.5	3.4*
Turbine Efficiency (%)	52.9	28.0
Turbine Flow Rate (lb/sec)	20.8	20.8*

* Fuel Turbopump Controls to Higher Flow Rate

b. Basis of Predictions

The predicted turbine performances result from a method of loss analyses based upon the following assumptions as modified by the data presented on Figures No. 83 through No. 93 for the selected design requirements.

(1) The inlet manifold loss level can be predicted from experimental cold flow test data.

(2) Blade row losses are a function of:

(a) Reynolds Number

(b) Nozzle Exit Angle

(c) Average Kinetic Energy

(d) Loss Coefficient

(3) Loss distribution between rotor and stator is a function of:

(a) Stage Loading

(b) Mean Blade Speed

Data were obtained from extensive cold flow testing of the NERVA Technology turbine inlet manifold as well as the experimental test results for the M-1 oxidizer turbine inlet manifold loss level. The common boundary layer assumption of loss variation in proportion to the one-fifth power was made for each blade row.

The nozzle exit angle was used to reflect the variation in the ratio of flow area to surface area. Its effect upon blade row loss is detailed in Reference 50.

The correlation of loss coefficient and stator-rotor loss distribution with experimental turbine test data for several turbine configurations is available in References 5 and 6.

The predicted centrifugal pump performances are based upon data demonstrated by Aerojet and modified by the data shown on Figures No. 67 through No. 82. In general, the difference in efficiency between low speed commercial pumps and high speed rocket engine pumps can be attributed to suction eye (inlet) size, inducer vane wrap, running clearances, and the hydraulic design of the impeller and collector flow passage.

The eye size is directly dictated by the suction performance requirements of the pump. High suction specific speeds require higher relative velocities and result in increased diffusion and friction losses.

Higher dynamic loads and less conservatively stressed components require high speed rocket pumps to operate with larger running clearances. These larger clearances result in lower performance and increased leakage rates which penalize efficiency.

At Aerojet, centrifugal pump efficiency is expressed as a function of pump specific speed, impeller discharge diameter, and pump suction specific speed. The discharge diameter, rather than the flow rate, is used to correlate efficiencies with specific speed because pump efficiency is more directly influenced by size for pumps of varying stage head rise and varying speed. Such influencing factors as clearance leakage, passage surface roughness, and fabrication accuracy are all directly dependent upon size.

Weights and lengths were estimated by calculations from the detailed layouts and account for selected materials, flanges out of plane, mounting provisions, bolts, and parts not shown. Although the layouts are fairly consistent for stress levels, none have been trimmed to the lowest possible weight. This is a function to be accomplished during final design.

2. Turbopump Optimization and Mechanical Design

Contractually negotiated funding restraints precluded the accomplishment of detailed turbopump optimizations and mechanical design. However, plans detailing such optimization were completed and the ensuing discussion of the fuel turbopump design serves to illustrate the method that would be applied.

a. Turbine Optimization

The turbine optimization study is divided into the following distinct activities:

(1) Turbine Parametric Analysis

Turbine parametric analysis consists of determining the relationship between the several turbine variables at the design point. The most significant of these variables are flow rate, pressure, shaft horsepower, and mean blade speed.

The method of analysis consists of determining losses for a given selection of operating conditions. The major assumptions for the analysis are as follows:

(a) One-dimensional flow at the mean radius.

(b) Adiabatic flow through static parts (i.e., manifold and nozzles).

(c) Losses can be grouped into three categories (i.e., inlet manifold loss, blading loss, and bearing loss).

(d) Blading losses are a function only of Reynolds Number, nozzle exit angles, and average kinetic energy level of the stage.

This method of analysis was programmed for the IBM 1130 computer and briefly, is as follows:

Step 1: Select the operating requirements for the turbine to establish inlet temperature, inlet pressure, power, and pressure ratio.

Step 2: Consider the mechanical properties of materials to be used to determine at least an approximate value for the mean blade speed.

Step 3: Select load distribution. Usually this selection is equal work per stage until the final turbine configuration is determined approximately.

Step 4: Select nozzle exit angles compatible with loading, desired blade geometry, and stage number.

Step 5: The type of velocity diagram for each stage is fixed by the degree of reaction selected for the stage.

Steps 1 through 5 provide the basic input for calculating mean blade velocity diagrams, blading losses, turbine flow rate, and performance. To obtain the optimum or near-optimum turbine for a given application, many of the above independent parameters are varied to permit study of their effect upon turbine performance.

The parameters which are interrelated to both turbine and engine performance are turbine inlet temperature, turbine inlet pressure, pressure ratio, mean blade speed, and rotational speed. Parameters which affect turbine performance as a component only are stage load distribution, nozzle angles, and degree of reaction.

The first group of parameters was studied as described in Task I with the intention of optimizing engine performance and cost whereas the second group would be studied to optimize turbine component performance.

In addition to performance analysis, the indicated computer program would be utilized to determine radial distributions in flow properties for the purpose of providing a basis for improved blade as well as nominal values for axial thrust.

The quantities determined at the blade hub and tip, in addition to the mean radius, are velocities, gas angles, pressures, temperatures, degree of reaction, and mach number. Blade heights and annulus areas also are determined.

The above parametric turbine analysis would provide the basis for selecting the detailed turbine configuration.

(2) Blade Stress and Weight Analysis

To provide consistency in the blade weight and the parametric stress analysis, a series of first and last stage blades would be designed using a technique similar to that discussed in Reference 7.

The weight of the blades in a turbine rotor determines the geometry and, hence, the weight of the turbine disc. Thus, blade weight dictates the weight of the entire turbine rotating assembly. The following sequential procedures are used to determine the total blade weight:

Step 1: The blade cross-sectional area is determined. This is coupled with the material density, blade height, and quantity of blades to obtain the weight for a "full weight" blade.

Step 2: The "full weight" blade weight then is reduced by 25% to obtain the value used for sizing the turbine discs. A 25% blade weight reduction can be accomplished by internal tapering.

The stresses exerted upon turbine blades can be categorized as:

- Centrifugal stress attributable to wheel rotation,
- Circumferential gas bending stress resulting from the circumferential momentum change,
- Axial gas bending resulting from the axial momentum change,
- Centrifugal bending stress caused by centroids not being located on a radial line,
- Secondary stresses attributable to vibration.

For the parametric study, only the centrifugal stress and circumferential gas bending stress are considered. In the analysis, the following assumptions would be made.

(a) The blade weight is 75% of the "full blade" weight.

(b) The height of the blade is divided up into four equal lengths, each length (commencing with the section at the blade root and proceeding to blade tip) having 10% less area than the preceding length. The resulting volume then is 75% of full volume.

(c) Centrifugal stress is maximum at blade root where the cross-sectional area is equal to 90% of the full vane area.

(d) Circumferential gas bending stress will be obtained from the speed, horsepower, work per stage, and the force being applied at one-half of the blade height.

(e) Gas bending stress is assumed to be maximum at the blade root trailing edge.

From the cross-section of each turbine blade, geometric properties are obtained by using a computer program. The summation of centrifugal and gas bending stress then can be obtained.

(3) Disc Stress and Weight Analysis

The disc configuration is simplified by using a section for preliminary analysis that consists of two isosceles trapezoids with sides that taper from the neck to the hub.

The nominal blade speed is varied between 1200 ft/sec and 1600 ft/sec. The rotational speed also is varied with a constant blade speed. The average gas temperature is varied between 1400°R and 1800°R.

The most attractive material appears to be Inconel 718, up to 1660°R. Above this, the stress rupture limitations of Inconel 718 indicate Rene' 41 could be best because its higher strength results in lighter discs.

The allowable average tangential disc stress is determined by fixing the burst speed at 1.44 times the nominal operating speed. The average tangential stress is a direct function of the blade radius and blade centrifugal force; the disc taper and minimum thickness have a small additional effect.

For Inconel 718, at a temperature of 1660°R, the allowable average tangential stress is 84,000 lb/in.^{2}.

Blade weight, blade speed, and material temperature directly affect the disc thickness. The tangential stress at the neck is limited to 45% of the design yield strength at the local temperature.

From the information obtained previously, the blade profile, weight, temperature, blade speed and blade mean diameter can be determined. The disc weight then can be determined as follows:

Step 1: From blade weight, mean diameter and speed, find the centrifugal blade force.

Step 2: Determine the centrifugal force of the blade platform and transition section to the neck.

Step 3: Knowing the allowable neck stress and combined force of blades and transition section, compute the neck thickness.

Step 4: With the known neck thickness, disc taper angle, and allowable average tangential disc stress, compute the disc volume and weight.

b. Pump Optimization

Three key pump parameters (i.e., shaft speed, pump suction specific speed, and impeller discharge angle) are evaluated in the pump optimization study for the selected engine. The three parameters are varied over representative ranges while the performance and weight are evaluated in terms of engine performance. Axial thrust is calculated for each case to allow those variations causing unacceptable bearing loads to be eliminated.

Step 1: Shaft speed is varied to investigate the performance advantage of increased specific speed and the weight advantage of decreased size.

Step 2: The suction specific speed of the impeller is varied over a wide range to evaluate the effect of impeller discharge to eye diameter proportions upon efficiency and weight.

Step 3: The impeller discharge angle of the main impeller is varied to determine the weight advantage of increased head coefficient (and smaller size). Efficiency remains fairly constant because the improved diameter ratio of the lower vane angle designs is offset by the higher friction losses of the longer blade passages. In evaluating this parameter, pump thrust becomes particularly significant.

The final selection of speed, specific speed, and discharge angle are based upon iterations of performance, weight, and length within allowable limits of stress, thrust (bearing load), bearing speed, and critical speed margin.

Complete summaries showing all parameters for all cases then are available to aid in refining the prediction of characteristics for various engine operating conditions as well as the selection of final design conditions once an engine operating point is fixed.

c. Supporting Mechanical Systems

The bearing analysis and design activity determines a thrust and radial bearing system with the optimum balance between severity of operation (speed and load) and reliability. A performance maximized, weight minimized turbopump requires high speed at high capacity and high radial stiffness. Reliability at acceptable life indicates the opposite. The optimum design balances these two criteria. The bearing design that results then is developed and improved until it meets the required load-life relationship. The design procedure includes the analytical approaches discussed below.

(1) Roller Bearings

The roller bearing parameters of primary interest for the design of a bearing system can be listed as follows:

- Spring Constant
- Hertz Stresses
- Basic Dynamic Load Rating
- Roller Centrifugal Force
- DN Value
- MRC Severity Factor K
- Hysteresis Heating

Spring constant of the roller bearing is an important consideration relative to rotor critical speed. For a given size turbopump with a given nominal speed and critical speed requirement, bearing spring constants determine bearing minimum size. The spring constant of a bearing is defined as the reciprocal of the bearing radial deflection under a given radial load. A computer program developed by New Departure solves for this variable. The equations solved are those developed by Hertz with modifications to account for the effect of bearing internal clearance. A possible mode of failure with the rolling contact bearing is metal fatigue at the contacting surfaces. Early fatigue failures can be caused by the repeated overstressing at the roller-to-raceway contacts. To evaluate the possibility of early fatigue failure caused by overstressing, Hertz contact stresses are computed using a computer program which solves the Hertzian equations for stress (both mean and maximum) and includes the effects of internal radial clearance.

Another parameter used to evaluate a potential fatigue problem is the specific dynamic capacity. The parameter also gives an estimate of bearing life (relative to fatigue failure) at speeds of interest. The calculations are based upon AFBMA formulae for basic load rating and life.

Hertz stresses of inner and outer raceways and dynamic load carrying capacity are affected by roller centrifugal force which is a function of roller size (bearing series) and bearing speed. As this parameter increases, outer race Hertz stresses increase, inner race stresses decrease, and bearing dynamic load capacity for a given bearing life (based upon fatigue) decreases. The indicated computer program calculates this parameter.

An indication of the severity of operation of a rolling element bearing is provided by the product of bearing bore in millimeters and shaft speed in revolution-per-minute (generally referred to as "DN Value"). This parameter does not differentiate between bearings of different series (proportions) where geometrical differences can significantly affect the effect of speed. DN values below 1.0×10^6 are not considered severe, values between 1.0×10^6 and 1.5×10^6 are moderate, while values of 2.0×10^6 are on the threshold of existing technology.

Perhaps a more realistic evaluation of the effect of speed as well as bearing size and geometry (especially relative to thrust bearings) is a parameter developed empirically by MRC. This severity factor, K, is expressed as follows:

$$K = P.D. \times (RPS)^3 \times d^3/(\cos \alpha)^3 \geq 31 \times 10^8$$

P.D. = Pitch dia in mm

RPS = Revolution per sec

d = Ball or roller dia., in.

α = Dynamic contact angle, degrees

For roller bearings, $\alpha = 0$, therefore

$$\cos \alpha = 1.0$$

$K = 31 \times 10^8$ appears to be too high for roller bearings, but discussions with MRC indicate it is a good upper limit.

(2) Ball Bearings

Ball bearings in tandem duplex or triplex sets can be used to support the net thrust load of the turbopump. The various design parameters for this bearing arrangement include those already discussed under roller bearings, except for spring constant, as well as the following:

- Dynamic Contact Angles (Inner and Outer Race)

- Inner and Outer Race Ratio of Shoulder Height to Ball Diameter

- Relative Spin Angular Velocity Between Ball and Inner and Outer Raceway Contacts

- Heat Generated Due to Ball Spin and Cage Friction

- Total Heat Generated by Bearing

- Bearing Life for 90% Probability of Survival

All of the above parameters, including those which pertain to ball bearings but already discussed under the roller bearing section, are calculated using an Aerojet Computer Program. A most important parameter of an angular contact high speed ball bearing is the dynamic contact angle at the inner and outer race. The dynamic contact angle is different at the two raceways because of ball centrifugal force and affects Hertz stresses, bearing load capacity, the MRC severity factor, K, and ball contact zone spin velocities.

The ball bearing must be capable of supporting high axial thrust loads. A limiting load is reached when the ball-to-raceway contact ellipse extends beyond the raceway shoulder height. Calculation of this parameter provides the limiting load for a particular bearing geometry.

An angular contact ball bearing operating at high speed has considerable spinning action at the ball-to-raceway contacts. The spinning velocity is a function of the dynamic contact angle which is dependent upon bearing geometry load and speed. The computer provides a calculation of the relative spin angular velocity between ball and raceway contacts (inner and outer). This velocity can be converted into the heat generated by ball spin, an important design factor. The combination of heat generated by ball spin, cage friction, and hysteresis (relatively small) provides the total heat generated by the bearing. This latter value is required to estimate the amount of LH_2 required to cool the bearing.

The computer program is set up to provide an estimate of bearing life for 90% probability of survival. It gives a rough indication of the life expectancy of the bearing under the severe conditions imposed because the life calculated is with respect to metal fatigue in a lubricated environment and, therefore, is not of real significance for this application.

d. Structural Dynamic Considerations

(1) Turbopump Critical Whirling Speeds and Bearing Loads

When a turbopump with rolling contact bearings is operated at or near a whirl critical speed, the bearing reactions and shaft bending stresses can become excessive. In addition, the shaft whirl deflections can be larger than the rotor-stator running clearances resulting in rotor rub problems. Should the bearing loads, shaft loads, or deflections become too large, the results could be catastrophic. Therefore, the importance of computing the whirl critical speeds and analyzing their influence upon turbopump operation is an area of major concern.

The analytical techniques used at Aerojet for predicting whirl critical speeds are rigorous, with proven reliability. Less rigorous techniques tend to overestimate the critical speeds resulting in higher bearing loads, reduced bearing life, and larger shaft deflections than predicted.

Over the past few years, several special shake and spin tests have been performed at Aerojet to permit analytical-experimental correlations. These correlations are:

LATERAL VIBRATION AND SPIN TEST CORRELATIONS

SYSTEM	TYPE OF TEST	NATURAL FREQUENCIES, CPS	
		TEST	ANALYTICAL
Titan Turbine Shaft	Shake Test	340	330
NERVA Technology Turbopump (Three-Stage Turbine)	Shake Test	1st -295 2nd -520	1st -305 2nd -522
Titan Task III High Speed Shaft	Shake Test	540	517
Titan Task III High Speed Shaft	Spin Test	550 + (1)	615
M-1 Fuel Turbopump	TPA Performance Test	258 + (2)	266

(1) This shaft was spin tested to 33,000 rpm (550 rps) and the shaft displacement instrumentation indicated the first critical to be above the maximum test speed. The whirl critical frequency is expected to be above the lateral natural frequency because of the "Gyroscopic Stiffening" effects.

(2) There were no special shake or spin tests performed with the M-1 Turbopump; however, on one occasion, during the TPA performance tests, the shaft speed reached 15,500 rpm (258 rps) where the accelerometer data indicated an increase in vibration level.

Whirl critical speed effects can be alleviated by one or a combination of the following techniques:

- Operation above the first or second critical speed (super-critical operation).

- Operation below the first critical speed (sub-critical operation).

- Sufficient damping to the system to limit the shaft amplitude and bearing response.

Supercritical operation has an inherent problem known as shaft instability. That is, even though the shaft speed is well above the first critical and not near another critical, it has been found that the shaft could start to whirl and cause rubbing, bearing failures, and fatigue failures in the casings. Moreover, stability problems are difficult to analyze and do not lend themselves to good prediction. To attain super-critical operation, the turbopump system must pass through the critical speed or speeds. The start transient of this turbopump is relatively slow and, therefore, severe damage could occur before the system could be accelerated through the critical speeds.

The shaft deflections and bearing response increase exponentially as the first whirl critical speed is approached. To ensure smooth subcritical operation, the turbopump speed must be sufficiently below the first whirl critical so that the bearing capacities are not exceeded and the shaft deflections are tolerable. Experience has shown that whirl instabilities do not occur when the shaft speed is maintained below the first critical speed. Experience also has shown that for safe operation, the first critical speed should be at least 1.15 times the maximum shaft speed.

The primary factors to be considered to maximize the first whirl critical speed are:

- Rotating system should be light weight.

- Rotating system should have high flexural stiffness.

- Bearing supports should be stiff.

- Bearing housing should be stiff.

- Distance from bearing to center of gravity of overhung components should be minimized.

Damping will not significantly change the whirl critical speeds, but it can limit the shaft deflections and bearing response for subcritical operation. Conversely, if the system is operated supercritical, the shaft deflections and bearing loads will be smaller without damping. With rolling contact bearings and a very low viscosity fluid (i.e., liquid hydrogen), damping is very small and cannot be expected to limit whirl amplitudes or bearing loads.

The method that is used to analyze the lateral vibration characteristics of the turbopump is a modified Myklestad-Thompson solution facilitated by a matrix formulation and programmed for digital computer application. The program has the capability of analyzing the free or forced-undamped, lateral vibration of two, elastically-coupled, lumped parameter beams. Natural frequencies, mode shapes, as well as associated shear and moment distributions can be computed. The program can compute the amplitudes of the shears, moments, slopes, and deflections attributable to harmonic forcing functions. Shear deflections, rotary inertia, and gyroscopic effects for rotating shaft analyses also are included in the program capability.

Subcritical operation is the most desirable for this turbopump. Cursory critical speed studies performed to date show that subcritical operation is possible.

The whirl critical speeds are sensitive to the nonlinear stiffness of the roller bearings and the bearing housing stiffness. Static roller bearing load-deflection tests are in progress to substantiate the predicted bearing stiffness.

(2) Turbine Rotor Stress

In the analysis of turbine rotors, the four main areas of concern are: stress profile in the discs; disc average tangential stress and burst speed; disc axial vibration and the corresponding axial critical speeds, and rotor blade stresses and vibrations. In addition to these four areas, its fatigue life is of interest, if the turbine rotor is highly stressed.

(a) Disc Stress Profile

One of the available proven techniques for determining the stress profile in a disc is a computer program for the finite element analysis of axisymmetric solids with nonlinear material properties. The finite element approach also has been found capable of predicting stress concentrations identical to those given by the mathematical theory of elasticity. The stress profile is influenced by the geometry of the wheel, bore, blades, drum, thermal gradient, centrifugal forces, differential pressure loads and overspeed prestressing.

(b) Average Tangential Stress and Burst Speed

As set forth in the literature, the following major factors influence the burst speed of a rotor:

- Material tensile strength
- Material ductility
- Uniformity of mechanical properties through the rotor
- Evenness of the stress distribution across the diametral section

These factors should be accounted for in predicting the burst speed. Usually, the burst speed is predicted by the following formula:

$$\text{Burst Speed, rpm} = \Omega \text{ rpm} \times \frac{\sigma \text{ Ult.} \times K}{\text{Average Tangential Stress at } \Omega \text{ rpm}}$$

where K = Utilization Factor Dependent on the previous mentioned factors.

σ_{Ult} = Appropriate value of tensile ultimate or stress rupture strengths.

The average tangential stress over the disc cross-sectional area may be obtained from the following well-known formula.

$$S_{DV} = 28.4 \quad \gamma\left(\frac{N}{1000}\right)^2 \left(\frac{I}{A}\right) + \frac{P}{2\pi A}$$

where S_{DV} = Average Tangential Stress of Disc, psi

γ = Specific Weight of Disc, lb per cu in.

I = Moment of Inertia of Disc Half-Section, About Centerline

N = Speed of Disc, rpm

A = Area of Disc Half Section, sq in.

P = Total Peripheral Load, lb

The turbine discs are sized to produce an average tangential stress low enough to cause the burst speed of the disc to be well above the operating range.

(c) Disc Axial Vibrations and Critical Speeds

Disc vibrations that have been found to be dangerous are the so-called nodal diameter type. A critical speed is the shaft speed which is equal to the quotient of a natural frequency of a nodal diameter mode divided by the number of nodal diameters. It is recommended that the difference between the critical and running speed be at least 15% for a two nodal diameter and 10% for the three and four nodal diameter type vibration modes.

A computer program is available to determine the natural frequencies of rotor discs. The validity of the program has been proven in numerous disc type rotor shake tests.

(d) Rotor Blade Stresses and Vibration

Two row turbines are utilized for the fuel turbopump concept. Each stage has a different blade design; therefore, the blade natural frequencies, both bending and torsional, are different. The number of blades and stators also vary resulting in different natural frequencies and corresponding resonant speeds for each stage. No actual checks of blade response were conducted during this study and the following discussion is intended only to illustrate the method of analysis.

Each blade passes "K" number of upstream nozzle vanes per revolution and is subject to NXK/60 pulses per second, where N is shaft speed in rpm. If the frequency of these pulses coincide with one of the rotor blade natural frequencies, a resonant magnification of the vibratory stress occurs. The dynamic magnification factor at resonance is limited only by the damping properties of the system. The speed at which resonance can occur is given by:

$$N_{Resonant} = \frac{60\ fm}{H\text{-}K}\ \text{rpm}$$

where f_m = Natural Frequency for Mode, m, in cps

H = Harmonic of Nozzle Passing Stimulus

As the pulses are not purely sinusoidal, the higher harmonics can occur.

K = Number of Upstream Nozzle Vanes per Revolution

The total damping of a rotating blade consists of three components: the inherent damping in the material; the aerodynamic damping of the high velocity gas around the blade; and the root damping consisting of friction between the rotor and the blade surfaces. To evaluate the root damping, the other forms of damping must be subtracted from the total experimental determined damping measurement.

Materials vary greatly in their internal damping characteristics and even for a particular material damping depends upon the magnitude and distribution of the blade stress level.

As a result of many tests in the M-1 Program, considerable experience exists with Inconel 718 rotor blades.

Analysis of the blades consists, first, of computing the stress levels caused by centrifugal, gas bending, and thermal environment. Next, the natural frequencies (both flexural and torsional mode) are computed utilizing either the classical hand calculations for a uniform, prismatic, unshrouded cantilevered beam or one of the numerous computer programs available for analyzing shrouded or unshrouded, uniform or non-uniform beams.

For blades having frequencies that can be excited within the operating range, a resonant stress analysis must be made.

The vibratory stress of the blades at the resonant frequencies can be determined by the following equation:

$$\sigma_{\text{vib @ resonance}} = \frac{(S)}{(H)} (\sigma_{\text{static}}) (R) \left(\frac{N}{N_o}\right)^2 (M.F.)$$

where S = Factor Expressing Fluctuation Amplitude (0.3)

H = Harmonic No. of Stimulus

R = Mode Receptiveness Factor (the response factor for a cantilever beam vibrating at the fundamental mode is approximately 0.87, at the second mode it is 0.066, and at the third mode it is 0.004

M.F. = Magnification Factor, at resonance with damping = $\frac{\pi}{\delta}$

Static = Stress caused by gas and centrifugal loading at speed N_o.

The blade cross-sections and the number of upstream stator nozzles can both be varied within the limits of turbine performance to obtain the most optimum interaction of blade natural frequency and nozzle excitation stimulus frequency. If a resonance condition must exist within the operating range, it must be made to occur at a low enough speed so that the magnified vibratory stress will be within the design limits. Blade fatigue is evaluated using the modified Goodman Diagram technique.

Cursory checks of the turbine blades proposed for this conceptual design indicate that even though a resonant speed is passed before the operating speed is reached, the resonant stress levels, when evaluated on the modified Goodman Diagram, will be within the design limits.

(3) Impeller Stress Analysis

A centrifugal impeller can be divided into two geometrical sections, the disc and the blade.

The techniques used in the analysis of the disc have been proven by numerous tests. Impeller discs have been stress analyzed using a digital computer program which is capable of handling any body of revolution subjected to a symmetric loading. Experience from previous similar impeller designs indicate the most critically stressed vanes are those in the inlet section. These vanes in the critical stress region generally approach flat plate configuration.

To achieve lightweight impeller designs, it is recognized that more accurate stress predictions than those typically used based upon calculation of the blade centrifugal force/pressure load stresses formulated for constant thickness circular plates and simple load distributions are required. To meet this need, Aerojet has developed a computer program for the solution of plates of arbitrary load conditions. This technique was used to analyze significant problems, for which exact solutions were available, to verify its accuracy.

(4) Turbopump Housing Structural Analysis

Two general objectives in the design of the housing are to obtain a low cost design and to maintain the high performance of the turbopump. The housings should be as light as possible without allowing high deformations that would require large nominal clearances between the rotating and stationary parts. Housing deformations are kept to a minimum by adequate stiffening, while considering the trade-off between cost and performance. In establishing design criteria, internal pressures and thermal environment are readily predictable. The dynamic loads are generally difficult to predict. The determination of the dynamic environment for this turbopump, however, could make use of previous test data from the NERVA Technology and M-1 Test Programs.

Proven methods would be applied in the stress analysis of the housing and volutes. The intersection of a pipe or line with a shell which will join the volute tangent to the shell inner and outer diameters offers a direct and immediate load path to the stiffer supporting structure. This results in minimum deformations and existing methods of analysis can be utilized.

IV. RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

A. RESULTS

1. Categorized Cost-Contributing Operations

There are seven major categories of cost-contributing operations associated with a turbopump during its usable life. These categories, which maintain strict separation between the development and production phases, are as follows:

- Development Design Operations
- Development Fabrication Operations
- Development Test Operations
- Production Design Operations
- Production Fabrication Operations
- Production Test Operations
- Production Field Maintenance Operations

Each of these broad categories consists of many detailed operations. These finer breakdowns are accomplished to the level appropriate for calculating the costs as detailed in Section III,A,1. An example of such a realistic level of listing is provided as Appendix B.

2. Categorized Design Requirements

All turbopump design requirements fall into the following three categories:

- Performance
- Operational
- Mechanical

However, all requirements must ultimately be reduced to the turbopump part level before a quantitative assessment of their influence upon costs can be accomplished. This was fully detailed in Section III,A,2 and is shown for the base case in Appendix C.

3. Relationship Between Variations in Requirements and Cost-Contributing Operations

Variations in the categorized requirements and cost-contributing operations were investigated in great detail as described in Section III,A,3 and Figures No. 5, No. 6, and No. 11 through No. 66. The relationships invariably show that the more stringent the requirement, the higher the technological level of the operations needed to sustain the requirement. This is not meant to imply that the highest over-all cost necessarily results from stringent requirements, rather it is only the cost of the affected operations which increases.

4. Description of Alternative Methods for Performing Cost-Contributing Operations and Recommendations for Additional Technology

Because of their relative importance (in terms of percentage of program costs), the most attractive area for utilizing alternative methods of performing cost-contributing operations are the production phase as well as the fabrication and test operations. In the referenced MLLV program, these contribute in excess of 82% of the turbopump program costs as shown on Table XI.

Many alternative methods for performing fabrication operations were investigated and are detailed in Section III,A along with pertinent plots (Figures No. 5, No. 6, and No. 11 through No. 66). Two such examples of alternatives are sandblasting instead of hand polishing machined or cast impellers to obtain the necessary surface finish and the casting instead of fully machining pump diffuser vanes to obtain the required vane profiles. Substantial cost savings in fabrication can be realized by using such alternatives where the appropriate technology is generally available. However, in each instance, it is necessary to evaluate the performance (hence, over-all cost) effect that will result from relaxing the pertinent requirements as shown in Section III,B and Figures No. 67 through No. 95. Additionally, the optimum method among available alternatives must be selected.

No reasonable alternative methods for performing the turbopump test operations are apparent. However, if the engine balance requirement can be relaxed or if turbopump performance repeatability can be improved, there is a possibility that the production phase testing could be eliminated. Such an approach would require experimental verification to validate its feasibility. A program of this type is strongly recommended. It would be conducted in the following sequence:

Step 1: Select an active engine production program wherein the engine balance requirements are known.

Step 2: Utilizing the data shown on Figures No. 67 through No. 95 and similar data generated for the selected program, revise the turbomachinery mechanical design requirements to obtain the necessary performance repeatability.

Step 3: Adjust the turbomachinery fabrication drawing per Step 2.

Step 4: Fabricate a reasonable sample (i.e., 10) of parts in accordance with the revised drawing.

Step 5: Test the sample turbopumps in the usual manner to verify that the theoretical performance repeatability has been achieved.

Step 6: Utilize the sample turbopumps in the selected production program.

The costs involved in the above recommended program are those associated with engineering to accomplish Steps 2 and 3 as well as those involved with evaluating the results of Step 5 and the increase in fabrication costs to produce the sample machines against more stringent requirements.

5. Relationship Between Turbopump Requirements and Cost

The relationship between requirements and cost was defined in rigorous detail at the turbopump level in terms of man/machine hours and prime (supplier charged) dollars. A grosser definition was evolved for several composite turbopump level alternatives in terms of program dollars applying a sample overhead structure. The detailed relationships between requirements and part costs were shown on Figures No. 5, No. 6, and No. 11 through No. 66. This relationship between requirements and turbopump costs with that of program costs were summarized on Tables VII and VIII.

6. Optimal Turbopump Requirements and Design Criteria

Turbopump design requirements were made optimum for the reference MLLV case and are included as Appendix L.

7. Low Over-All Cost Turbopump Conceptual Designs and Associated Development, Production, and Acceptance Plans

A brief optimization study was accomplished using the reference (contract specified) performance requirements. This resulted in the selection of the basic mechanical configurations shown on Figures No. 1 and No. 2. Conceptual design was limited to selecting the design requirements listed in Appendix L and the predicted performance shown on Table XII. Although detailed optimizations and mechanical designs were not accomplished, the method for accomplishing them is detailed in Section III,C,2. The associated development, production, and acceptance plans were shown on Figure No. 4.

B. CONCLUSIONS

The most significant conclusions and implications which became apparent during the course of the program as well as from the results of the study are summarized in the ensuing discussions.

1. Requirements Influence Level

Generally, the design requirements influence upon the cost of operations is apparent at the part or feature level only.

2. Program Size Implications

In terms of over-all program cost, the relative importance of any category of operations performed in association with the turbopump is very strongly influenced by the size of the production program assumed. Any reasonably high production program (where delivered units exceed research units by at least one order of magnitude) costs are of a nature that individual costs (excluding production, phase fabrication, and test operations costs) probably are lower than the estimating tolerance for the production, fabrication, and test costs. Clearly, the elimination of all development phase costs from the reference program would result in less than a 5% reduction in the turbopump program costs and an almost indiscernible decrease in over-all program costs.

3. Individual Operations Cost Implications

A lack of visibility of costs for individual operations in any size program at the level where they are influenced by the requirements is apparent although as individual operations they might constitute a high proportion of the component costs.

4. Synthesis of Designs

Based upon the conclusions detailed, the synthesis of optimal turbopump requirements and design criteria from individual requirements versus cost of operations data is both imperative to low over-all cost and so unwieldy that it becomes virtually impossible because of the almost infinite number of microscopic effects to be considered.

C. RECOMMENDATIONS

The results of the study indicate that costs not be attacked at the individual requirement and operation level in an effort to reduce the cost of operations. Instead, it is recommended that costs be attacked at the major operations category level with the objective of eliminating the entire category. In keeping with this philosophy and based upon the results of Tasks I and II, it is further recommended that methods be investigated to eliminate production phase turbopump acceptance testing. The Rocketdyne Division of North American-Rockwell undertook an effort of this type during the latter portions of their J-2 program effort.

The requirement to perform turbopump acceptance tests results from the desire to make a mechanical check of the turbopump functional capability as well as to obtain calibration or balance data for subsequent engine checkout and calibration testing. Actually, at the reliability levels of current rocket engine turbomachinery, the only function served by the turbopump acceptance test is to provide engine balance data. Therefore, if turbopump performance repeatability (from unit to unit) can be achieved within the engine balance requirements, the turbopump acceptance tests can be eliminated with the engine calibration test serving as the turbopump functional and performance calibration checkout.

It is recognized that to accomplish what is recommended requires some technological development so as to obtain the needed performance repeatability. However, much of the technology needed to accomplish this largely is available from this Low Cost Turbopump Study. The cost of sustaining individual part level mechanical design requirements is known as well as their influence upon performance. Therefore, the only data necessary for performing the necessary trade-off is the relationship between part level mechanical design requirements and performance repeatability as such. This extension in the data provided herein, along with experimental verification of the results would constitute a relatively straightforward technology development program which could provide major reductions (up to 40%) in future program turbopump costs.

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APPENDIX A

TYPICAL FUEL TURBOPUMP PRELIMINARY DESIGN CALCULATIONS

Pump

Known

$\dot{W}_p$ = 125 lb/sec - 13,000 gpm

ΔP = 1900 psi - 64,000 ft

NPSH = 130 ft

Assume

$$S \approx 90{,}000 \frac{RPM\ (GPM)^{1/2}}{NPSH^{3/4}}$$ Max (From M-1 & J-2 experience)

For $\phi_{IT} = 0.08$

$$\text{Then } N = \frac{S(NPSH)^{3/4}}{Q^{1/2}}$$

$$= 30{,}800 \text{ rpm} \quad \text{Say } 30{,}000$$

$$N_s = \frac{N\ Q^{1/2}}{\Delta H^{3/4}}$$

$$= 855$$

Select $\beta 2 = 30°$ and $\psi 2 = 0.55$ from experience

Then $\eta_p = 0.70$ from empirical curves

for $\phi_2 = 0.10$

$$U_{2T} = \left(\frac{g\Delta H}{\psi_2}\right)^{1/2}$$

$$= 1935 \text{ ft/sec}$$ OK for titanium disc

The sizes are:

$$D_{IT} = \left\{\frac{93.6\ Q}{N\phi_{IT}(1-RH^2)}\right\}^{1/3}$$

$$= \boxed{8.40 \text{ in.}}$$

$$D_{IH} = R_H \times D_{IT}$$

$$= \boxed{3.20 \text{ in.}}$$

$$D_{2T} = \frac{229\ U}{N}$$

$$= \boxed{14.75 \text{ in.}}$$

$$h_2 = \frac{Q \times 144}{449\ \pi\ D_{2T}\ C_{m2}\ (1\text{-Blockage})}$$

$$= \boxed{0.58 \text{ in.}}$$

Turbine

Known

T_i = 1660°R

P_i = 1140 psia

γ = 1.363

R = 403

C_p = 1.95

PR = 7.5

P_2 = 152 psia

Assume

U_m = 1300 FPS (reasonable for 718 @ 1660°R)

K_{noz} = 0.94 (empirical loss coefficient)

Calculate

$$c_o = 2g\ K_{noz}\ C_p\ J\ Ti\ [1 - (\frac{1}{PF})]^{\frac{\gamma-1}{\gamma}}$$

$$= 7940 \text{ ft/sec}$$

Then U/C = 0.164 and

$$\left.\begin{aligned} \eta &= 0.53 \\ K_1 &= 0.78 \\ K_2 &= 0.86 \\ K_3 &= 0.90 \end{aligned}\right\} \quad \text{from design curves}$$

Solution of the velocity triangles and design equations then yields

ΔV_{WT} = 13,980 ft/sec

$\dot{W}_T$ = 20 lb/sec

T_2 = 1250°F

η_t = 53.5%

and sizes are

$$\left.\begin{aligned} h_1 &= 0.92 \text{ in.} \\ h_2 &= 1.05 \text{ in.} \end{aligned}\right\} \quad \text{Rotor Blade Heights}$$

$$\left.\begin{aligned} C_1 &= 0.86 \text{ in.} \\ C_2 &= 0.78 \text{ in.} \end{aligned}\right\} \quad \text{Rotor Chord Lengths}$$

d_1 = 3.65 in. Manifold inlet dia for 0.25 Mach No.

d_2 = 2.58 in. Split torus dia for 0.25 Mach No.

APPENDIX B

COST-CONTRIBUTING OPERATIONS

I. <u>DEVELOPMENT PHASE OPERATIONS</u>

A. DESIGN OPERATIONS

1. <u>Analysis</u>

a. Hydraulic/Aerodynamic Performance

b. Hydraulic/Aerodynamic Loads

c. Thermal Conditions

2. <u>Mechanical Design</u>

a. Critical Speed Determination

b. Structural Analysis

(1) Static stress/deflection analysis.

(2) Inertia stress/deflection analysis.

(3) Dynamic stress/deflection analysis.

(4) Thermal stress/deflection analysis.

c. Drafting

(1) Layouts

(2) Part fabrication drawings

(3) Assembly processing drawings

d. Checking

3. <u>Fabrication Follow-Up</u>

4. <u>Test Planning and Follow-Up</u>

B. DEVELOPMENT FABRICATION OPERATIONS

1. <u>Advance Vendor Quotes/Consulting</u>

2. <u>Procurement Processing/Planning</u>

3. <u>Tooling Fabrication</u>

4. <u>Rawstock Procurement</u>

5. <u>Casting or Forging</u>

6. <u>Machining</u>

7. <u>Welding</u>

8. <u>Subassembly</u>

9. <u>Assembly</u>

10. <u>Final Assembly (Engine)</u>

11. <u>Inspection</u>

12. <u>Outside Liaison</u>

13. <u>Inside Liaison</u>

14. <u>Shipping</u>

C. DEVELOPMENT TEST OPERATIONS

1. <u>Subcomponent Test (Part or Feature Level)</u>

a. Subcomponent Proof Tests

(1) Rotor Proof Spin Tests

(2) Housing Pressure Tests

b. Subcomponent Integrity Evaluation

(1) Vibration Characteristics Definition (Blading)

(2) Housing Burst Pressure

(3) Rotor Burst Speed

(4) Bearing Life Tests

2. <u>Component Tests (Subassembly Level)</u>

a. Pump Performance Evaluation

b. Power Transmission Performance Evaluation

c. Turbine Performance Evaluation

3. Turbopump Development Tests

   a. Performance Evaluation

   b. Life/Reliability Evaluation

   c. Malfunction Survival Evaluation

4. Turbopump Acceptance Tests (Checkout for R&D Engines)

II. PRODUCTION/OPERATIONAL PHASE OPERATIONS

A. DESIGN OPERATIONS

1. Performance Modifications to Meet Changine Engine Requirements

2. Mechanical Modifications to Meet Life/Reliability Under Unanticipated (Field Test Results) Environments

B. PRODUCTION FABRICATION OPERATIONS

1. Procurement Processing/Planning

2. Tooling Fabrication

3. Rawstock Procurement

4. Casting or Forging

5. Machining

6. Welding

7. Subassembly

8. Assembly

9. Final Assembly (Engine)

10. Inspection

11. Outside Liaison

12. Inside Liaison

13. Storage

14. Shipping

C. PRODUCTION TEST OPERATIONS

1. <u>Subcomponent Level Tests</u>

   a. Rotor Proof Spin Tests

   b. Housing Proof Pressure Tests

2. <u>Component Level Tests</u>

   a. Pump Calibration

   b. Turbine Calibration

3. <u>Turbopump Level Tests</u>

   a. Acceptance Tests

   b. Post-Test Checkout and Inspections

4. <u>Engine Level Tests</u>

   a. Engine Acceptance Tests

   b. Post-Test Checkout and Inspections

5. <u>Stage Level Tests</u>

   a. Flight Readiness Tests

   b. Post-Test Checkout and Inspections

D. FIELD MAINTENANCE AND REPAIR OPERATIONS

1. <u>Seal Checks</u>

2. <u>Seal Replacement (Interfaces)</u>

3. <u>Torque Checks</u>

4. <u>Removal and Replacement</u>

APPENDIX C

CATEGORIZED BASE CASE VEHICLE, ENGINE AND TURBOPUMP DESIGN REQUIREMENTS

DESIGN REQUIREMENTS

CATEGORY/LEVEL	PARAMETER	REQUIREMENT	BASIS
Performance/Engine & Stage	Thrust	300,000 lb	Contract work statement
	Thrust Tolerance	± 3%	M-1 Engine Value
	Thrust Chamber Pressure	1200 psia	Contract work statement
	Thrust Chamber Pressure Tolerance	± 1.5%	F, I_s, MR tolerance
	Specific Impulse	433 sec	Assumes = 50, I_s = 95% theory, 3% turbine bleed, turbine I_s = 225 sec
	Specific Impulse Tolerance	+ 3 sec	M-1 Engine Value
	Mixture Ratio (Engine)	5:1	J-2 Engine Value
	Mixture Ratio Tolerance (Engine)	2.5%	M-1 Engine Value
	Mixture Ratio (G.G.)	.90	To give 1660°R
	Fuel Flow Rate	116 lb/sec	F, I_s, MR above
	Oxidizer Flow Rate	580 lb/sec	F, I_s, MR above
Performance/Fuel Turbopump	Pump Pressure Rise	1900 psia	Typical J-2 & M-1 losses
	Pump Pressure Rise Tolerance	± 3%	Typical component variations
	Pump Flow Rate	125 lb/sec	F, I_s, MR above + bearing/ balancer flow
	NPSH (Minimum)	130 ft	Typical vehicle value
	Turbine Inlet Pressure	1190 psia	$P_{cgg} = P_c$ = duct loss
	Turbine Pressure Ratio	7.5	Pre-Design
	Turbine Inlet Temperature	1660°R	State-of-the-art uncooled material properties.
	Turbine Inlet Temperature Tolerance	250°R	MR operating envelope & thrust balance
	Static Seal Leakage	"Negligible")	Typical performance values (see operational requirements)
	Dynamic Seal Leakage	.05 lb/sec)	

CATEGORY/LEVEL	PARAMETER	REQUIREMENT	BASIS
Performance/Oxidizer Turbopump	Pump Pressure Rise	1700 psia	Typical M-1, J-2 losses
	Pump Pressure Rise Tolerance	± 3%	Typical 3 component variations
	Pump Flow Rate	585 lb/sec	F, I_s, MR above + bearing/ balancer flow
	NPSH (Minimum)	25 ft	Typical vehicle value
	Turbine Inlet Pressure	135 psia	Pre-Design
	Turbine Pressure Ratio	3.4	Pre-Design
	Turbine Pressure Ratio Tolerance	± 2%	Typical 3 component variations
	Turbine Inlet Temperature	1250°F	Pre-Design
	Turbine Inlet Temperature Tolerance	± 180°	MR operating envelope & thrust balance
	Static Seal Leakage	"Negligible")	Typical performance values (see operational requirements)
	Dynamic Seal Leakage	.05 lb/sec)	
Operational/Stage & Engine	Throttling	None	Typical launch vehicle requirement
	Startup Duration	3 sec	Typical launch vehicle requirement
	Duty Cycle	4 starts 300 sec	Engine acceptance & balance tests, stage FRF & launch
	In Flight Restarts	None	
	Pre Start Childown	-400°F fuel pump	Typical launch vehicle requirement
		-280°F Oxidizer pump	Typical launch vehicle requirement
	Static Seal Leakage	5 psi decay in 20 min from 50 psig GN_2 leak test	Typical engine requirement
	Dynamic Seal Leakage	.05 lb/sec	Typical requirement

CATEGORY/LEVEL	PARAMETER	REQUIREMENT	BASIS
	Environment	GN_2 or dry air blanket except during launch preparation	Typical environment
	Reliability (Engine Duty Cycle)	.97	Typical value
	Schedule	6 years to 1st R&D flight	Preliminary program plan
Operational/Turbopumps	Same as engine except as follows:		
	Duty Cycle	5 starts 300 sec	Engine firings + turbopump acceptance test
	Static Seal Leakage	2 psi decay in 20 min from 50 psig GN_2 leak test	Apportioned engine leak rate
	Reliability	.998	Apportioned from engine requirement Titan value
Mechanical/Turbopumps	Design Life	10 hours)	Titan values which resulted in above reliability for similar duty cycle
	Design Firings	10 starts)	
Mechanical/Turbopumps Subcomponents	See part by part listing on the following pages of this table.		

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Bearing Housing/Backplate, Fuel (1)		
Size (O.D.)	25.0 in	22-32 in
Material	Cast 347	Cast 347
Surface Finish	63	250
Tolerance		
Pilot Dia's	± .001	± .005
Bearing Dia's	± .0005	± .0005
Axial Dimensions	± .001	± .005
Quality Control	Current Aerospace *	Minimum**
Shaft, Fuel (2)		
Size (Bearing Dia.)	2.25 in	2-3.5 in
Material	Inconel X	Inconel X
Tolerance		
Diameters	± .0005	± .0005
Axial Dimensions	± .001	± .010
Surface Finish	16/63	16/63
Quality Control	Current Aerospace	Minimum
Dynamic Balance	Required	Required

* 100% Dimensional, Material Certification & Traceability

** Critical Dimensions only, Material Certification & Traceability

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Bearings, Fuel (3) (4) (6) (7)		
Size	60mm	50-90 min
Number/Type	4/Preloaded Ball)	
Material	440C/Armalon)-----------	No Change
Class	5)	
Quality Control	Current Aerospace	
Spacer, Bearing-Upper & Lower (3.5) (6.5)		
Size (O.D.)	2.750	2.5-3.5 in
Material	Inconel X)	
Tolerance	)	
Diameter	$\pm$ .0005)-----------	No Change
Surface Finished	16/63)	
Quality Control	Current Aerospace)	
Turbine Shaft Coupling, Fuel (8)		
Size (O.D.)	5.5 in	5-8 in.
Material	Inconel X	Inconel X
Surface Finish	16/63	16/63
Tolerance		
Diameters	$\pm$ .0005	$\pm$ .0005
Axial Dimensions	$\pm$ .001	$\pm$ .010
Quality Control	Current Aerospace	Minimum
Dynamic Balance	Required	Required

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Bolt, Shaft Coupling (9)		
Size (Thread Diameter)	1.125 in.	1-2 in.
Material	Inconel X	
Tolerance		
Diameter	± .0005)	
	± .010)	
Thread	Class A)	----------- No Change
Concentricity	.001)	
Surface Finish	32/63)	
Quality Control	Current Aerospace)	
Nut, Coupling (10)		
Size (O.D.)	1.5 in.	1.25 - 3.0 in.
Material	A 286	A 28
Tolerance		
Thread	.625 Class A	.5-1.0 Class A
Squareness	.001	.001
Surface Finish	63	63
Quality Control	Current Aerospace	Minimum
Labyrinth, Shaft (11)		
Size (O.D.)	4.5 in.	4-6 in.
Material	Phosphor Bronze	Phosphor Bronze
Tolerance		
Diameter	± .001/-.000	± .002
Squareness	.001	.005

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Surface Finish	32/63	32/63
Quality Control	Current Aerospace	Minimum
Carrier, Bearing - Upper (12)		
Size (O.D.)	4.25 in.	4-7 in.
Material	Inconel X	
Tolerance		
Diameter	+ .0000	
	- .0005	No Change
Concentricity	.001	
Surface Finish	16/63	
Quality Control	Current Aerospace	
Carrier, Bearing - Lower (13)		
Size (O.D.)	4.25 in.	4-7 in.
Material	Inconel X	
Tolerance		
Diameter	+ .0000	
	- .0005	No Change
Concentricity	.001	
Surface Finish	16/63	
Quality Control	Current Aerospace	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Spacer, Shim-Bearing Retaining (14)		
Size (O.D.)	5.0 in.	4.5 - 7.5 in.
Material	Inconel X	
Tolerance		
Diameter	.001	
Parallelism	.001	No Change
Surface Finish	63	
Quality Control	Current Aerospace	
Spacer, Bearing Retaining (15)		
Size (O.D.)	5.0 in.	4.5 - 7.5 in.
Material	Inconel X	
Tolerance		
Diameter	.001	No Change
Parallelism	.001 (or less)	
Surface Finish	63	
Quality Control	Current Aerospace	
Labyrinth, Coupling (16)		
Size (O.D.)	5.0 in.	4-5 - 7.5 in.
Material	Phosphor Bronze	Phosphor Bronze
Tolerance		
Diameter	± .0005	± .002
Flatness	.0005	.005
Surface Finish	63	63
Quality Control	Current Aerospace	Minimum

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Turbine Seal, Fuel (17)		
Type	Shaft Riding	Labyrinth
Size (I.D.)	2.5 in.	2.25 - 4.0 in.
Tolerance		
Flange Dimensions	± .010	± .010
Sealing Elements	± .0005	± .001
Quality Control		
1st Stage Turbine Rotor, Fuel (18)		
Size (O.D.)	10.8 in.	8-16 in.
Material	Forged 718	Forged 718
Surface Finish	63	125
Tolerance		
Blade	± .003	± .010
Diameters & Axial Dim's	± .001	± .005
Quality Control	Current Aerospace	Minimum
Dynamic Balance	Required	Required
2nd Stage Turbine Rotor, Fuel (19)		
Size (O.D.)	10.8 in.	8-16 in.
Material	Forged 718	Forged 718
Surface Finish	63	250
Tolerance		
Blade	± .003	± .010
Diameters	± .001	± .010
Quality Control	Current Aerospace	Minimum
Dynamic Balance	Required	Required

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Bolt, Turbine Rotor (20)		No Change
Size (shank)	.375	
Material	718	
Tolerance		
Diameters	$\pm$ .0005	
Tir	.001	
Surface Finish	32	
Quality Control	Current Aerospace	
Stator Vane, Fuel Turbine (21)		
Size (O.D.)	12.6 in.	12-20 in.
Material	Forged 718	Cast 718
Tolerance		
Vane Profile	$\pm$ .003	$\pm$ .010
Diameters	$\pm$ .003	$\pm$ .003
Surface Finish	63	250
Quality Control	Current Aerospace	Minimum
Low Pressure Orifice, Fuel (22)		
Size (O.D.)	7.0 in.	6-9 in.
Material	718	347/Flame Plate
Tolerance		
Diameters	$\pm$ .003	$\pm$ .003
Flatness	$\pm$ .001	$\pm$ .001
Surface Finish	32	63
Quality Control	Current Aerospace	Minimum

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Nut, Ring Orifice - Low Pressure (23)		
Size (O.D.)	6.75 in.	6-9 in.
Material	347	347
Tolerance		
Diameters	$\pm$ .0005	$\pm$ .010
Squareness	.001	$\pm$ .001
Surface Finish	63	63
Quality Control	Current Aerospace	Minimum
Ring, Orifice-High Pressure (27)		
Size (O.D.)	16.0 in.	14-22 in.
Material	Inconel 718	347/Flame Place
Tolerance		
Diameters	$\pm$ .003	$\pm$ .003
Flatness	$\pm$ .001	$\pm$ .001
Surface Finish	32	63
Quality Control	Current Aerospace	Minimum
Nut, Ring Oridice-High Pressure (28)		
Size (O.D.)	16.0 in.	14-22 in.
Material	347	347
Tolerance		
Diameter (O.D.)	Class A Thread	Class A Thread
(I.D.)	.001	$\pm$ .010
Squareness	.001	$\pm$ .001
Surface Finish	63	63
Quality Control	Current Aerospace	Minimum

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Pump Diffuser, Fuel (29)		
Size (Base Circle Dia.)	15.5 in.	14-22 in.
Material	347	Cast Aluminum
Surface Finish	63	250
Vane Tolerance	± .003	± .010
Diameter Tolerance	± .003	± .010
Quality Control	Current Aerospace	Minimum
Impeller, Fuel (30)		
Size (O.D.)	14.6 in.	12-21 in.
Material	Forged Titanium	Forged Titanium
Surface Finish	63	250
Vane Tolerance	± .003	± .010
Diameter Tolerance	± .003	± .010
Quality Control	Current Aerospace	Minimum
Dynamic Balance	Required	Required
Inducer, Fuel (31)		
Size (O.D.)	8.4 in.	8-10 in.
Material	Forged Titanium	Forged Titanium
Surface Finish	63	250
Vane Tolerance	± .003	± .010
Diameter Tolerance	± .003	± .010
Quality Control	Current Aerospace	Minimum
Dynamic Balance	Required	Required

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Nut Assy, Impeller Retaining (32)		
Size (O.D.)	3.1 in.	3-4 in.
Material	Aluminum	Aluminum
Tolerance		
Diameter (Thread)	Class A	Class A
(I.D.)	$\pm$ .001	$\pm$ .030
Contour Thickness	$\pm$ .002	$\pm$ .030
Surface Finish	63	125
Quality Control	Current Aerospace	Minimum
Pump Housing, Fuel (34)		
Size (O.D. - 180° Sect)	24.0 in.	21-32 in.
Material	Cast 347	Cast 347
Surface Finish	63/125	125/250
Tolerance		
Volute	$\pm$ .03	$\pm$ .10
Contour	$\pm$ .003	$\pm$ .010
Pilots	$\pm$ .001	$\pm$ .005
Quality Control	Current Aerospace	Minimum
Housing, Bearing Oxid (1)		
Size (O.D.)	5.9 in	3-7 in.
Material	347	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Surface Finish	32/63*)	
Tolerance	)	
Pilot Dia's	± .001)	No Change
Bearing Dia's	± .0005)	
Axial Dimensions	± .001)	
Quality Control	Current Aerospace)	
Shaft, Oxid (2)		
Size (Bearing Dia.)	2.4 in.	2-3.5 in.
Material	Inconel X)	
Tolerance	)	
Diameters	± .0005)	No Change
Axial Dimensions	± .001)	
Surface Finish	16/63)	
Quality Control	Current Aerospace)	
Dynamic Balance	Required)	
Bearings, Oxid (3) (13)		
Size	60mm	50-90mm
Number/Type	2/Preloaded Ball)	
Material	440C/Armalon)	
Class	5)	No Change
Quality Control	Current Aerospace)	

* Bearing Surface I.D.

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Seal Assy, Bellows-Upper Oxid (4)		
Size (O.D.)	6.2 in.	5.5 - 8.0 in.
Material	347)	
Tolerance	)	
Diameters	± .001)	
Flatness (Seal Surface)	1 Helium Light Band)	--- No Change
Type	Purged & Vented Dual Seal)	
Quality Control	Current Aerospace)	
Axial Tolerance	± .001)	
Surface Finish (347 Material)	63)	
Seal Ring, Running-Upper Oxid (5)		
Size (O.D.)	3.4 in.	3-5 in.
Material	347)	
Surface Finish	63)	
Seal Face (Flame Plated)	Ground & Lapped)	
Diameters O.D.	± .001)	
Diameters I.D.	± .0005)	----------- No Change
Axial Dimensions Tolerance	± .001)	
Quality Control	Current Aerospace)	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Seal Ring, Running-Lower Oxid (6)		
Size (O.D.)	5.0 in.	4-7 in.
Material	347	
Surface Finish	63	
Seal Faces (2) (Flame Plated)	Ground & Lapped	
Tolerance		No Change
Diameter I.D.	± .0005	
Axial Dimension	± .001	
Squareness	.0005	
Quality Control	Current Aerospace	
Seal Assy, Shaft Riding Oxid (7)		
Size (O.D.)	6.6 in.	5.5 - 8 in.
Material	347	
Surface Finish	63	
Tolerance		
Diameter (O.D.)	± .001	No Change
Axial Dimensions	± .001	
Squareness	± .0005	
Quality Control	Current Aerospace	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Seal Assy, Bellows-Lower Oxid (8)		
Size (O.D.)	6.6 in.	5.5 - 8 in.
Material	347)	
Tolerance	)	
Diameters	$\pm$ .001)	---- No Change
Axial Dimensions	$\pm$ .001)	
Flatness (Seal Surface)	1 Helium Light Band)	
Type	Purged & Vented Dual Seal)	
Quality Control	Current Aerospace)	
Surface Finish (347 Material)		
Nut, Seal Retaining, Oxid (9)		
Size (O.D.)	6.8 in.	6-8.5 in.
Material	Inconel X)	
Tolerance	)	
Diameters (O.D. Thread)	Class A)	----------- No Change
(I.D.)	.003)	
Squareness	.001)	
Surface Finish	63)	
Quality Control	Current Aerospace)	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Filter, Oxid (10)		
Size (O.D.)	5.3 in.	4.5 - 7.5 in.
Rating	10 Micron)	
Material	CRES 300)	
Tolerance	)	
Diameter (O.D.)	.030)	No Change
Diameter (I.D.)	.001)	
Axial Dimensions	.010)	
Surface Finish (Machined Ends)	63)	
Quality Control	Current Aerospace)	
Spacer, Bearing, Oxid (12)		
Size (O.D.)	3.0 in.	2.5 - 4 in.
Material	Inconel X)	
Tolerance	)	
Diameter (O.D.)	$\pm$ .005)	No Change
Diameter (I.D.) (Pilot)	$\pm$ .0005)	
Squareness	.001)	
Surface Finish	32 I.D. & Ends Only)	
Quality Control	Current Aerospace)	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Nut, Bearing Retaining, Oxid (14)		
Size (O.D.)	3.3 in.	2.5 - 4.5 in.
Material	A286	
Tolerance		
Diameter (O.D.)	± .010	No Change
(I.D.) Thread	Class A	
Flatness	.001	
Surface Finish	63	
Quality Control	Current Aerospace	
Seal, Labyrinth-Lower, Oxid (15)		
Size (O.D.)	12.0	10.0 - 16.0 in.
Material	KEL-F	KEL-F
Tolerance		
Diameter (O.D.)	± .010	± .010
(I.D.)	± .002	± .005
(Pilot)	± .002	± .005
Concentricity	.002	.002
Quality Control	Current Aerospace	Minimum

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Retainer, Labyrinth-Lower, Oxid (16)		
Size (O.D.)	12.8 in.	11.0 - 17.0 in.
Material	Aluminum	
Tolerance		
Diameter (O.D.)	± .003	
(I.D. Pilot)	± .002	No Change
Squareness	.002	
Surface Finish	63	
Quality Control	Current Aerospace	
Volute, Pump, Oxid. (17)		
Size (O.D.) (360° Section)	23 in.	21-29 in.
Material	Cast Aluminum	Cast Aluminum
Surface Finish	63/126	63/250
Tolerances		
Flow Passage	± .030	± .10
Pilot Diameters	± .001	± .003
Axial Stack Up Dimensions	± .003	± .010
Quality Control	Current Aerospace	Minimum

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Nut, Volute Pump Retaining, Oxid (18)		
Size (O.D.)	5.8 in.	5-8 in.
Material	Inconel X	
Diameters (O.D.)	± .010	
(I.D. Thread)	Class A	No Change
Squareness	± .001	
Surface Finish	63	
Quality Control	Current Aerospace	
Impeller, Oxid (19)		
Size (O.D.)	13 in.	11-19 in.
Material	Shell Mold-Cast Aluminum	Investment Cast Aluminum
Vane Tolerance	± .025	± .010
Tip Tolerance	± .010	± .010
Sealing Surface Tolerance	± .002	± .010
Pilot Diameter Tolerance	± .0005	± .0005
Axial Stackup Tolerance	± .010	± .010
Squareness	.001	.001
Dynamic Balance	Required	Required
Surface Finish	63	63/250
Quality Control	Current Aerospace	Minimum

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Inducer, Oxid (20)		
Size (O.D.)	8.1 in.	7.9 - 10 in.
Material	Forged Aluminum	Die Cast Aluminum
Tolerance		
Vane	± .005	± .015
Diameters (O.D.)	± .005	± .005
Pilots	± .0005	± .0005
Axial Stack Up	± .010	± .010
Squareness	.001	.001
Dynamic Balance	Required	Required
Surface Finish	63	63/125
Quality Control	Current Aerospace	Minimum
Bolt, Impeller Retaining, Oxid (21)		
Size (O.D.)	.8 in.	.5 - 2.0 in.
Material	K-Monel)	
Tolerance	)	
Diameters - Pilot	± .001)	
Thread	Class A)	----------- No Change
Other	± .010)	
Squareness	± .001)	
Quality Control	Current Aerospace)	
Surface Finish	63)	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Seal, Labyrinth-Upper, Oxid (22)		
Size (O.D.)	10.6 in.	10 - 12 in.
Material	KEL-F	KEL-F
Tolerance		
Diameter (O.D.)	± .010	± .010
(I.D.)	± .002	± .005
(Pilot)	± .002	± .005
Concentricity	.002	.002
Quality Control	Current Aerospace	Minimum
Spacer, Seal-Labyrinth, Oxid (23)		
Size (O.D.)	11.7 in.	11 - 13 in.
Material	Aluminum	
Tolerance		
Diameter (O.D.)	± .010	No Change
(Pilot)	± .002	
(I.D.)	± .005	
Surface Finish	63	
Quality Control	Current Aerospace	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Retainer, Labyrinth-Upper, Oxid (24)		
Size (O.D.)	11.72 in.	11 - 13 in.
Material	Aluminum	No Change
Tolerance		No Change
Diameter (O.D.)	± .003	No Change
(Pilots)	± .002	No Change
(I.D.)	± .003	No Change
Squareness	± .001	No Change
Surface Finish	63	No Change
Quality Control	Current Aerospace	No Change
Adapter, Pump Inlet, Oxid (25)		
Size (O.D.)	14.5 in.	14 - 22 in.
Material	Cast Aluminum	Cast Aluminum
Tolerance		
Diameter (O.D. Pilots)	± .002	± .005
(O.D.)	± .030	± .100
(I.D. Bore)	± .002	± .010
(I.D. at Labyrinth)	± .001	± .001
Squareness (at Labyrinth)	.001	.003
Surface Finish	63	250
Quality Control	Current Aerospace	Minimum

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Rotor, Turbine, Oxid (26)		
Size (O.D.)	19.5 in.	18 - 28 in.
Material (Forging)	Inconel 718	Cast 718
Surface Finish	63	125
Tolerance		
Blades	$\pm$ .003	$\pm$ .010
Diameters	$\pm$ .001	$\pm$ .005
Quality Control	Current Aerospace	Minimum
Dynamic Balance	Required	Required
Bolt, Rotor, Oxid (27)		
Quantity	6 ea.	6 - 10 ea.
Size	3/8 dia. x 1.85 long	
Material	A-286	
Tolerance	Class A Thread	
Diameter (O.D.)	$\pm$ .001	No Change
Surface Finish	32	
Quality Control	Current Aerospace	

SUBCOMPONENT/REQUIREMENT	BASE VALUE	ALTERNATE RANGE
Manifold, Turbine Inlet, Oxid (28)		
Size (Torus O.D.)	24.7 in.	22 - 32 in.
Material (Cast. Formed & Welded)	Inconel 718	347
Tolerance		
Diameters	± .003	± .010
Vane Profiles	± .003	± .010
Surface Finish, Vanes	63	250
Quality Control	Current Aerospace	Minimum

APPENDIX D

FAILURE MODE ANALYSES

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LOW-COST FUEL TURBOPUMP (1136900)
AND
LOW-COST OXIDIZER TURBOPUMP (1137000)

FAILURE MODE ANALYSIS
LOW COST FUEL TURBOPUMP
(1136900)

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
INDUCER					.999694
	VANE FAILURE			204.3	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	B-1	1.0	
		OSCILLATING PRESSURE STRESS	B-1	1.0	
		THERMAL LC FATIGUE	B-1	1.0	
		SHAFT DEFLECTION/RUB	B-2	100.0	
		CENTRIFUGAL GROWTH/RUB	A-1	.1	
		HOUSING DISTORTION/RUB	B-1	1.0	
		SHAFT FIT/RUB	A-1	.1	
		MATERIAL STRENGTH	B-2	100.0	
	HUB FAILURE			101.4	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	A-1	.1	
		OSCILLATING PRESSURE STRESS	B-1	1.0	
		SHAFT FIT	A-1	.1	
		CLUTCH SHEARING	A-1	.1	
		MATERIAL STRENGTH	B-2	100.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
INDUCER RETAINER					.999995
	SHANK FRACTURE			1.2	
		TENSILE STRESS	A-1	.1	
		TORQUE STRESS	B-1	1.0	
		MATERIAL STRENGTH	A-1	.1	
	THREAD FRACTURE			.4	
		SHEAR LOAD	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	
		THREAD SIZE	A-1	.1	
		THREAD FORM	A-1	.1	
	LOOSE STACK-UP			3.0	
		THERMAL INCOMPATIBILITY	B-1	1.0	
		DAMAGED THREAD	A-2	1.0	
		LOCK TANG NOT ENGAGED	A-2	1.0	
IMPELLER					.999370
	VANE FAILURE			224.2	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	C-1	10.0	
		OSCILLATING PRESSURE STRESS	B-2	100.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	VANE FAILURE (Continued)				
		THERMAL LC FATIGUE	B-1	1.0	
		SHAFT DEFLECTION/RUB	C-1	10.0	
		CENTRIFUGAL GROWTH/RUB	A-1	.1	
		HOUSING DISTORTION/RUB	B-1	1.0	
		MATERIAL STRENGTH	B-2	100.0	
		HIGH THRUST/RUB	B-1	1.0	
		DISC DEFLECTION/RUB	B-1	1.0	
	DISC FAILURE			101.3	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	A-1	.1	
		OSCILLATING PRESSURE STRESS	B-1	1.0	
		THERMAL STRESS	A-1	.1	
		MATERIAL STRENGTH	B-2	100.0	
	BALANCER RUB			203.3	
		HOUSING DISTORTION	B-1	1.0	
		CONTAMINATION	B-2	100.0	
		CENTRIFUGAL DISTORTION	A-1	.1	
		TURBINE THRUST	B-1	1.0	
		CRITICAL SPEED	B-1	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	BALANCER RUB (Continued)				
		PRESSURE DISTORTION	A-1	.1	
		AXIAL VIBRATION (ND MODES)	A-1	.1	
		MATING FACE RETENTION	B-2	100.0	
				101.3	
	CLUTCH FAILURE				
		SPLINE SIZE	A-1	.1	
		SPLINE FORM	A-1	.1	
		HIGH TORQUE	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	
		NOT FULLY ENGAGED	B-2	100.0	
					.999788
IMPELLER RETAINER					
				10.2	
	SHANK FRACTURE				
		TENSILE STRESS	A-1	.1	
		TORQUE STRESS	A-3	10.0	
		MATERIAL STRENGTH	A-1	.1	
				.4	
	THREAD FRACTURE				
		SHEAR LOAD	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	
		THREAD SIZE	A-1	.1	
		THREAD FORM	A-1	.1	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	LOOSE STACK-UP			201.0	
		THERMAL INCOMPATIBILITY	B-1	1.0	
		DAMAGED THREAD	B-2	100.0	
		LOCK TANG NOT ENGAGED	B-2	100.0	
PUMP BEARINGS					.999670
	FATIGUE			126.0	
		SHAFT FIT/INTERFERENCE	B-1	1.0	
		CARTRIDGE FIT/INTERFERENCE	B-1	1.0	
		SHAFT FIT/UNBALANCE	B-1	1.0	
		CARTRIDGE FIT/LOOSE (CRIT SPED)	C-1	10.0	
		CRITICAL SPEED	C-1	10.0	
		MISALIGNMENT	A-2	1.0	
		MATERIAL STRENGTH	A-2	1.0	
		CLAMPING LOAD HIGH OR UNEVEN	A-2	1.0	
		CARTRIDGE BINDING	B-2	100.0	
	MECHANICAL			202.0	
		CAGE STRENGTH	B-1	1.0	
		CAGE WEAR	D-1	100.0	
		CONTAMINATION	A-4	100.0	
		COOLANT ADEQUACY	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	FACE FRACTURE			2.0	
		SHAFT FIT	B-1	1.0	
		MATERIAL STRENGTH	A-2	1.0	
TURBINE BEARINGS					.999462
	FATIGUE			434.0	
		HIGH THRUST	B-1	1.0	
		SHAFT FIT/INTERFERENCE	B-1	1.0	
		CARTRIDGE FIT/INTERFERENCE	C-1	10.0	
		SHAFT FIT/UNBALANCE	C-1	10.0	
		CARTRIDGE FIT/LOOSE (CRIT SPD)	D-1	100.0	
		CRITICAL SPEED	C-1	10.0	
		MISALIGNMENT	A-2	1.0	
		MATERIAL STRENGTH	A-2	1.0	
		CLAMPING LOAD	B-2	100.0	
		CARTRIDGE BINDING	B-2	100.0	
		CARTRIDGE POSITION	B-2	100.0	
	MECHANICAL			102.0	
		CAGE STRENGTH	B-1	1.0	
		CAGE WEAR	D-1	100.0	
		CONTAMINATION	A-4	100.0	
		COOLANT ADEQUACY	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	RACE FRACTURE			2.0	
		SHAFT FIT	B-1	1.0	
		MATERIAL STRENGTH	A-2	1.0	
TURBINE ROTOR (1)					.999072
	DISC FAILURE			311.2	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	A-1	.1	
		OSCILLATING PRESSURE STRESS	C-1	10.0	
		AXIAL VIBRATION	D-1	100.0	
		MATERIAL STRENGTH	A-2	1.0	
		STRESS CONCENTRATION	B-2	100.0	
		LABYRINTH RUB	B-2	100.0	
	BLADE FAILURE			515.5	
		CENTRIFUGAL STRESS	A-1	.1	
		GAS BENDING STRESS	A-1	.1	
		OSCILLATING GAS BENDING	B-1	1.0	
		AMPLIFIED OSC GAS BENDING	D-1	100.0	
		MATERIAL STRENGTH	A-2	1.0	
		RUB-BLADE CREEP	A-1	.1	
		RUB-DISC CREEP	A-1	.1	
		RUB-CENTRIFUGAL GROWTH	A-1	.1	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	BLADE FAILURE (Continued)				
		RUB-SHAFT DEFLECTION	B-1	1.0	
		RUB-HOUSING DISTORTION	C-1	10.0	
		RUB-SHAFT FIT	B-2	100.0	
		RUB-AXIAL VIBRATION	D-1	100.0	
		RUB-THERMAL DISTORTION	D-1	100.0	
		RUB-HIGH THRUST	B-1	1.0	
		RUB-FOREIGN OBJECTS	B-2	100.0	
		RUB-CRITICAL SPEED	B-1	1.0	
	COUPLING FAILURE			101.3	
		COUPLING SIZE	A-1	.1	
		HIGH TORQUE	A-1	.1	
		COUPLING FORM	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	
		NOT FULLY ENGAGED	B-2	100.0	
TURBINE ROTOR (2)					.999171
	DISC FAILURE			311.2	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	A-1	.1	
		OSCILLATING PRESSURE STRESS	C-1	10.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	DISC FAILURE (Continued)				
		AXIAL VIBRATION	D-1	100.0	
		MATERIAL STRENGTH	A-2	1.0	
		STRESS CONCENTRATION	B-2	100.0	
		LABYRINTH RUB	B-2	100.0	
	BLADE FAILURE			416.5	
		CENTRIFUGAL STRESS	A-1	.1	
		GAS BENDING STRESS	A-1	.1	
		OSCILLATING GAS BENDING	B-1	1.0	
		AMPLIFIED OSC GAS BENDING	D-1	100.0	
		MATERIAL STRENGTH	A-2	1.0	
		RUB-BLADE CREEP	A-1	.1	
		RUB-DISC CREEP	A-1	.1	
		RUB-CENTRIFUGAL GROWTH	A-1	.1	
		RUB-SHAFT DEFLECTION	B-1	1.0	
		RUB-HOUSING DISTORTION	C-1	10.0	
		RUB-SHAFT FIT	B-2	1-0.0	
		RUB-AXIAL VIBRATION	D-1	100.0	
		RUB-THERMAL DISTORTION	B-1	1.0	
		RUB-HIGH THRUST	B-1	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	BLADE FAILURE (Continued)				
		RUB-FOREIGN OBJECTS	B-2	100.0	
		RUB-CRITICAL SPEED	B-1	1.0	
	COUPLING FAILURE			101.3	
		COUPLING SIZE	A-1	.1	
		HIGH TORQUE	A-1	.1	
		COUPLING FORM	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	
		NOT FULLY ENGAGED	B-2	100.0	
TURBINE MANIFOLD					.999853
	HOUSING BURST			12.2	
		MATERIAL STRENGTH	A-2	1.0	
		OVERPRESSURE	A-1	.1	
		OVERTEMPERATURE	A-1	.1	
		WELD DEFECTS	A-3	10.0	
		THICKNESS VARIATIONS	A-2	1.0	
	LEAKAGE			112.0	
		POROSITY	A-2	1.0	
		WELD DEFECTS	A-3	10.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	LEAKAGE (Continued)				
		SEALS	B-2	100.0	
		BOLTS	B-1	1.0	
	NOZZLE FAILURE			23.0	
		THERMAL LC FATIGUE	C-1	10.0	
		HOUSING DISTORTION	C-1	10.0	
		FLUTTER	B-1	1.0	
		PRESSURE LOAD	B-1	1.0	
		MATERIAL STRENGTH	A-2	1.0	
TURBINE NOZZLE (2)					.999873
	VANE FAILURE			23.1	
		THERMAL LC FATIGUE	C-1	10.0	
		FLUTTER	B-1	1.0	
		PRESSURE LOAD	B-1	1.0	
		HOUSING DISTORTION	C-1	10.0	
		DIAPHRAGM LOAD	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	
	INTERSTAGE LEAK			104.0	
		FLANGE DISTORTION	B-1	1.0	
		ECCENTRICITY	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	INTERSTAGE LEAK (Continued)				
		FLANGE FIT	A-2	1.0	
		LABYRINTH FIT	A-2	1.0	
		LABYRINTH RUB	B-2	100.0	
	GAS MISDIRECTION			.2	
		STATOR ROTATION	A-1	.1	
		VANE DISTORTION	A-1	.1	
PUMP HOUSING					.999894
	HOUSING BURST			2.1	
		MATERIAL STRENGTH	A-2	1.0	
		OVERPRESSURE	A-1	.1	
		THICKNESS VARIATIONS	A-2	1.0	
	LEAKAGE			102.0	
		POROSITY	A-2	1.0	
		SEALS	B-2	100.0	
		BOLTS	B-1	1.0	
	VANE FAILURE			2.2	
		HOUSING DISTORTION	A-1	.1	
		PRESSURE LOAD	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	VANE FAILURE (Continued)				
		VANE FORM (LOCAL DEFECTS)	A-2	1.0	
BEARING HOUSING					.999898
	HOUSING BURST			1.2	
		MATERIAL STRENGTH	A-1	.1	
		OVERPRESSURE	A-1	.1	
		BEARING INTERFERENCE	A-2	1.0	
	LEAKAGE			101.0	
		POROSITY	A-2	1.0	
		SEALS	B-2	100.0	
TURBINE SEAL					.999695
	EXCESS FLOW			302.0	
		LABYRINTH CLEARANCE	A-2	1.0	
		LABYRINTH RUB	B-2	100.0	
		BLOCKED VENT	A-2	1.0	
		CARBON BREAK	B-2	100.0	
		CARBON WEAR	B-2	100.0	
	HIGH TORQUE			3.0	
		LABYRINTH FIT	A-2	1.0	
		PILOT CONCENTRICITY	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	HIGH TORQUE (Continued)				
		THERMAL DISTORTION	B-1	1.0	
SHAFT					.999891
	SHEAR FRACTURE				
		HIGH TORQUE	A-1	.2	
		MATERIAL STRENGTH	A-1	.1	
	FATIGUE			.1	
		MISALIGNMENT LOADS	B-1	4.1	
		STRESS CONCENTRATIONS	A-2	1.0	
		MATERIAL STRENGTH	A-1	1-0	
		CRITICAL SPEED	B-1	.1	
		UNBALANCED	B-1	1.0	
	DAMAGING RUB			1.0	
		CRITICAL SPEED	B-1	4.0	
		INSUFFICIENT CLEARANCE	A-2	1.0	
		MISALIGNMENT	B-1	1.0	
		UNBALANCE	B-1	1.0	
	SPLINE SHEAR			100.4	
		HIGH TORQUE	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	SPLINE SHEAR (Continued)				
		SPLINE FORM	A-1	.1	
		NOT FULLY ENGAGED	B-2	100.0	
		SPLINE SIZE	A-1	.1	
TURBINE COUPLING					.999899
	SPLINE SHEAR			100.4	
		HIGH TORQUE	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	
		SPLINE FORM	A-1	.1	
		NOT FULLY ENGAGED	B-2	100.0	
		SPLINE SIZE	A-1	.1	
	SHEAR FRACTURE			.2	
		HIGH TORQUE	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	

FAILURE MODE ANALYSIS
LOW COST OXIDIZER TURBOPUMP
(1137000)

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
INDUCER					.999694
	VANE FAILURE			204.3	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	B-1	1.0	
		OSCILLATING PRESSURE STRESS	B-1	1.0	
		THERMAL LC FATIGUE	B-1	1.0	
		SHAFT DEFLECTION/RUB	B-2	100.0	
		CENTRIFUGAL GROWTH/RUB	A-1	.1	
		HOUSING DISTORTION/RUB	B-1	1.0	
		SHAFT FIT/RUB	A-1	.1	
		MATERIAL STRENGTH	B-2	100.0	
	HUB FAILURE			101.4	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	A-1	.1	
		OSCILLATING PRESSURE STRESS	B-1	1.0	
		SHAFT FIT	A-1	.1	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	DISC FAILURE - (CONTINUED)				
		SPLINE SHEARING	A-1	.1	
		MATERIAL STRENGTH.	B-2	100.0	
INDUCER/IMPELLER RETAINER					.999995
	SHANK FRACTURE			1.2	
		TENSILE STRESS	A-1	.1	
		TORQUE STRESS	B-1	1.0	
		MATERIAL STRENGTH	A-1	.1	
	THREAD FRACTURE			.4	
		SHEAR LOAD	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	
		THREAD SIZE	A-1	.1	
		THREAD FORM	A-1	.1	
	LOOSE STACK-UP			3.0	
		THERMAL INCOMPATABILITY	B-1	1.0	
		DAMAGED THREAD	A-2	1.0	
		LOCK TANG NOT ENGAGED	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
					.999370
IMPELLER				224.2	
	VANE FAILURE				
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	C-1	10.0	
		OSCILLATING PRESSURE STRESS	B-2	100.0	
		THERMAL LC FATIGUE	B-1	1.0	
		SHAFT DEFLECTION/RUB	C-1	10.0	
		CENTRIFUGAL GROWTH/RUB	A-1	.1	
		HOUSING DISTORTIONS/RUB	B-1	1.0	
		MATERIAL STRENGTH	B-2	100.0	
		HIGH THRUST/RUB	B-1	1.0	
		DISC DEFLECTION/RUB	B-1	1.0	
	DISC FAILURE			101.3	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	A-1	.1	
		OSCILLATING PRESSURE STRESS	B-1	1.0	
		THERMAL STRESS	A-1	.1	
		MATERIAL STRENGTH	B-2	100.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	LABYRINTH RUB (FORE & AFT)			203.3	
		HOUSING DISTORTION	B-1	1.0	
		CONTAMINATION	B-2	100.0	
		CENTRIFUGAL DISTORTION	A-1	.1	
		TURBINE THRUST	B-1	1.0	
		CRITICAL SPEED	B-1	1.0	
		PRESSURE DISTORTION	A-1	.1	
		AXIAL VIBRATION (ND MODES)	A-1	.1	
		MATING FACE RETENTION	B-2	100.0	
	SPLINE FAILURE			101.3	
		SPLINE SIZE	A-1	.1	
		SPLINE FORM	A-1	.1	
		HIGH TORQUE	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	
		NOT FULLY ENGAGED	B-2	100.0	
PUMP BEARING					.999770
	FATIGUE			26.0	
		SHAFT FIT/INTERFERENCE	B-1	1.0	
		HOUSING FIT/INTERFERENCE	B-1	1.0	
		SHAFT FIT/UNBALANCE	B-1	1.0	
		HOUSING FIT/LOOSE (CRIT SPD)	C-1	10.0	
		CRITICAL SPEED	C-1	10.0	
		MISALIGNMENT	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	FATIGUE (CONTINUED)				
		MATERIAL STRENGTH	A-2	1.0	
		CLAMPING LOAD HIGH OR UNEVEN	A-2	1.0	
	MECHANICAL			202.0	
		CAGE STRENGTH	B-1	1.0	
		CAGE WEAR	D-1	100.0	
		CONTAMINATION	A-4	100.0	
		COOLANT ADEQUACY	A-2	1.0	
	RACE FRACTURE			2.0	
		SHAFT FIT	B-1	1.0	
		MATERIAL STRENGTH	A-2	1.0	
TURBINE BEARING					.999662
	FATIGUE			234.0	
		HIGH THRUST	B-1	1.0	
		SHAFT FIT/INTERFERENCE	B-1	1.0	
		HOUSING FIT/INTERFERENCE	C-1	0.0	
		SHAFT FIT/UNBALANCE	C-1	0.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	FATIGUE (CONTINUED)				
		HOUSING FIT/LOOSE (CRIT SPD)	D-1	100.0	
		CRITICAL SPEED	C-1	10.0	
		MISALIGNMENT	A-2	1.0	
		MATERIAL STRENGTH	A-2	1.0	
		CLAMPING LOAD HIGH OR UNEVEN	B-2	100.0	
	MECHANICAL			102.1	
		CAGE STRENGTH	B-1	1.0	
		CAGE WEAR	D-1	100.0	
		CONTAMINATION	A-1	.1	
		COOLANT ADEQUACY	A-2	1.0	
	RACE FRACTURE			2.0	
		SHAFT FIT	B-1	1.0	
		MATERIAL STRENGTH	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
TURBINE ROTOR					.999172
	DISC FAILURE			211.2	
		CENTRIFUGAL STRESS	A-1	.1	
		PRESSURE STRESS	A-1	.1	
		OSCILLATING PRESSURE STRESS	C-1	10.0	
		AXIAL VIBRATION	D-1	100.0	
		MATERIAL STRENGTH	A-2	1.0	
		STRESS CONCENTRATION	B-2	100.0	
	BLADE FAILURE			515.5	
		CENTRIFUGAL STRESS	A-1	.1	
		GAS BENDING STRESS	A-1	.1	
		OSCILLATING GAS BENDING	B-1	1.0	
		AMPLIFIED OSC GAS BENDING	D-1	100.0	
		MATERIAL STRENGTH	A-2	1.0	
		RUB-BLADE CREEP	A-1	.1	
		RUB-DISC CREEP	A-1	.1	
		RUB-CENTRIFUGAL GROWTH	A-1	.1	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	BLADE FAILURE (CONTINUED)				
		RUB-SHAFT DEFLECTION	B-1	1.0	
		RUB-HOUSING DISTORTION	C-1	10.0	
		RUB-SHAFT FIT	B-2	100.0	
		RUB-AXIAL VIBRATION	D-1	100.0	
		RUB-THERMAL DISTORTION	D-1	100.0	
		RUB-HIGH THRUST	B-1	1.0	
		RUB-FOREIGN OBJECTS	B-2	100.0	
		RUB-CRITICAL SPEED	B-1	1.0	
	COUPLING FAILURE			101.3	
		COUPLING SIZE	A-1	.1	
		HIGH TORQUE	A-1	.1	
		COUPLING FORM	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	
		NOT FULLY ENGAGED	B-2	100.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
TURBINE MANIFOLD					.999853
	HOUSING BURST			12.2	
		MATERIAL STRENGTH	A-2	1.0	
		OVERPRESSURE	A-1	.1	
		OVERTEMPERATURE	A-1	.1	
		WELD DEFECTS	A-3	10.0	
		THICKNESS VARIATIONS	A-2	1.0	
	LEAKAGE			112.0	
		POROSITY	A-2	1.0	
		WELD DEFECTS	A-3	10.0	
		SEALS	B-2	100.0	
		BOLTS	B-1	1.0	
	NOZZLE FAILURE			23.0	
		THERMAL LC FATIGUE	C-1	10.0	
		HOUSING DISTORTION	C-1	10.0	
		FLUTTER	B-1	1.0	
		PRESSURE LOAD	B-1	1.0	
		MATERIAL STRENGTH	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
PUMP HOUSING					.999894
	HOUSING BURST			2.1	
		MATERIAL STRENGTH	A-2	1.0	
		OVERPRESSURE	A-1	.1	
		THICKNESS VARIATIONS	A-2	1.0	
	LEAKAGE			102.0	
		POROSITY	A-2	1.0	
		SEALS	B-2	100.0	
		BOLTS	B-1	1.0	
	VANE FAILURE			2.2	
		HOUSING DISTORTION	A-1	.1	
		PRESSURE LOAD	A-1	.1	
		MATERIAL STRENGTH	A-2	1.0	
		VANE FORM (LOCAL DEFECTS)	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
					.999898
BEARING HOUSING					
				1.2	
	HOUSING BURST				
		MATERIAL STRENGTH	A-1	.1	
		OVERPRESSURE	A-1	.1	
		BEARING INTERFERENCE	A-2	1.0	
				101.0	
	LEAKAGE				
		POROSITY	A-2	1.0	
		SEALS	B-2	100.0	
					.999594
				403.0	
TURBINE SEAL					
	EXCESS FLOW	COCKED CARBON	B-2	100.0	
		BROKEN CARBON	A-2	1.0	
		COCKED ROTATING RING	B-2	100.0	
		CARBON WEAR	B-2	100.0	
		LABYRINTH CLEARANCE	A-2	1.0	
		LABYRINTH RUB	B-2	100.0	
		BLOCKED VENT	A-2	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	HIGH TORQUE			3.0	
		LABYRINTH FIT	A-2	1.0	
		PILOT CONCENTRICITY	A-2	1.0	
		THERMAL DISTORTION	B-1	1.0	
SHAFT					.999693
	SHEAR FRACTURE			.2	
		HIGH TORQUE	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	
	FATIGUE			202.1	
		MISALIGNMENT LOADS	B-2	100.0	
		STRESS CONCENTRATIONS	A-2	1.0	
		MATERIAL STRENGTH	A-1	.1	
		NEAR CRITICAL SPEED	B-2	100.0	
		UNBALANCE	B-1	1.0	
	DAMAGING RUB			4.0	
		CRITICAL SPEED	B-1	1.0	
		INSUFFICIENT CLEARANCE	A-2	1.0	
		MISALIGNMENT	B-1	1.0	
		UNBALANCE	B-1	1.0	

PART	MODE	MECHANISM	RATING	RFP	RELATIVE RELIABILITY
	SPLINE SHEAR			100.4	
		SPLINE SIZE	A-1	.1	
		HIGH TORQUE	A-1	.1	
		SPLINE FORM	A-1	.1	
		MATERIAL STRENGTH	A-1	.1	
		NOT FULLY ENGAGED	B-2	100.0	

APPENDIX E

SAMPLE ESTIMATE FOR BASE CASE FUEL TURBOPUMP SUBCOMPONENTS FROM LAMCO INDUSTRIES, INC.

LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 2

PLANNER CHG. N/C	CUSTOMER DOC REVIEW SGN	SERIAL NO.	PART NO. ITEM #1	CHG LTR N/C	W.O. PARTS - IN STORE	QTY	W.S. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE 347 CRES ~~(POSSIBLE~~ CASTING)	PART NAME BEARING HOUSING	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1156900	HEAT NO.				EXP DATE

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND TURN CRITICAL CONTROL DIAMETERS									LAFX	
			AND MACHINED CONFIGURATION (REF SKETCH)									(PIC-JAW)	
	48 40 HRS		DIAMETER	"A"	23.000	+.001 -.000						TCTP	
	45		CONTOUR "	B	15.000	±.002							
			CONTROLLED "	C	16.500	+.001 -.000							
			AREA "	D	7.000	+.001 -.000							
			THREAD		6.500	CL "A"							
			DIAMETER (2) PLS	F	4.250	±.0005							
			"	G	5.200	±.001							
			HOLD CONCENTRICITY		⊙ .001 TIR								
			FINISH		63	UNLESS NOTED							
			DEBURR COMPLETE		.005	MAX							
30	MILL		SETUP AND MACHINE ALL LOCATING									MLFX	
	10 10 HRS		PADS AND AREAS REQ'D FOR BOLT										
	15		INSTALLATION AND CONNECTORS										

LTR	CHANGE

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LAMCO INDUSTRIES, INC.

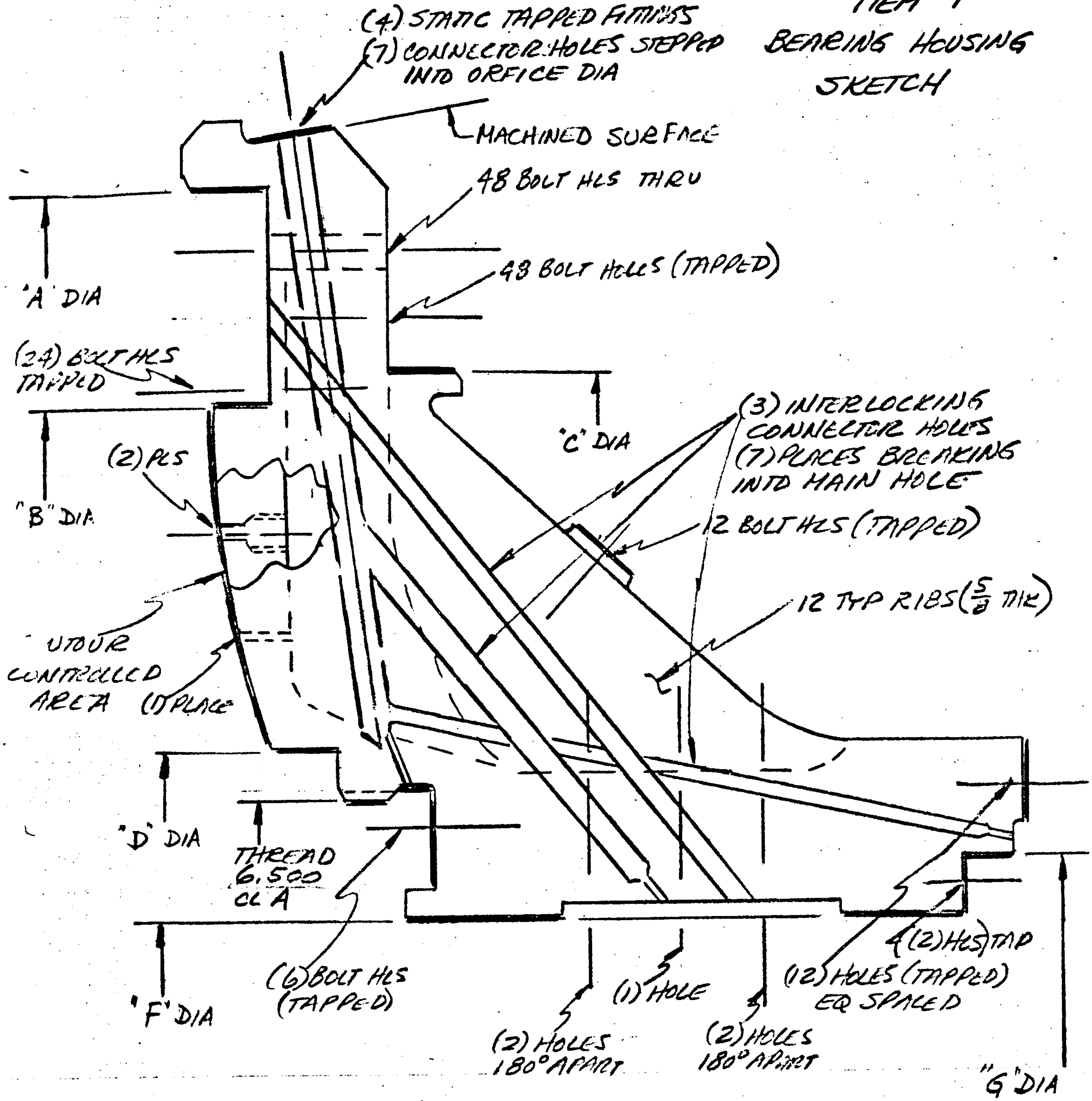
SHEET 2 OF 2

PLANNER CHG	CUSTOMER	PART NAME	PART NO.	CHG LTR	W/O NO.
N/C	AGC	BEARING HOUSING	ITEM #1	N/C	8132

OPER NO.	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM.	TOL.	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
35	JIGBORE		SETUP + DRILL/TAP (10) VARIOUS HOLE PATTERNS									HOLDING FIXTURE	
	BRIDGEPORT 48 HRS												
40	50 DRILL		USE DRPE + DRLJ TO DRILL HOLES									DREX #1	
	PRESS		DRILL (48) HOLE PATTERN (2) LOCATIONS									DRFX # 2	
	40		HOLD DIMS ⌀.005									DRFX #3	
	30 HRS												
	60		DRILL (12) HOLE PATTERN (2) LOCATIONS									DRFX #4	
			HOLD DIMS ⌀.005										
			DRILL (6) HOLE PATTERN (1) PLACES ⌀.005										
			DRILL (24) HOLE PATTERN (1) PLACE ⌀.005										
50	JIGBORE		DRILL/BORE ALL CONNECTOR HOLES									(HOLDING FIXTURE)	HOFX
	BRIDGEPORT		AND ORFICE HOLES PER B/P REQ'MENTS										
	100		(28) PCS HOLD DIMS ⌀.005										
	100 HRS												
	110												
60	SHOP		TAP ALL HOLES PER B/P									HOFX	
	20		CLEAN + DEBURR COMP .005 MAX										
	10 HRS		DO NOT MAR 63/ FINISHES										
	20												
70	INSP		INSP THROUGH OPER 60										
80	PROCESS		PROCESS PART PER B/P										
90	P/C		STORE FOR N/ASSY										
			OR [illegible] FOR										
			SHIP[illegible] TO CUSTOMER										

FORM NO. L-2

ITEM #1
BEARING HOUSING
SKETCH



PERFECTO CAST - BEARING HOUSING, FUEL

$2100	TOOLS
$2000	1 PART
$1400	10 PARTS
$1250	40 PARTS

LAMCO INDUSTRIES, INC.

SHEET 2 OF 2

PLANNER CHG	CUSTOMER	PART NAME	PART NO.	CHG LTR	W/O NO.
N/C	AGC	SHAFT	IRM #2	N/C	8132

OPER NO.	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM.	TOL.	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
50	INSP		INSP THROUGH OPER	40									
60	PROCESS		PROCESS PART PER B/P										
70	P/C		STORE FOR N/ASSY OR PREPARE FOR SHIPPING TO CUSTOMER										

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LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

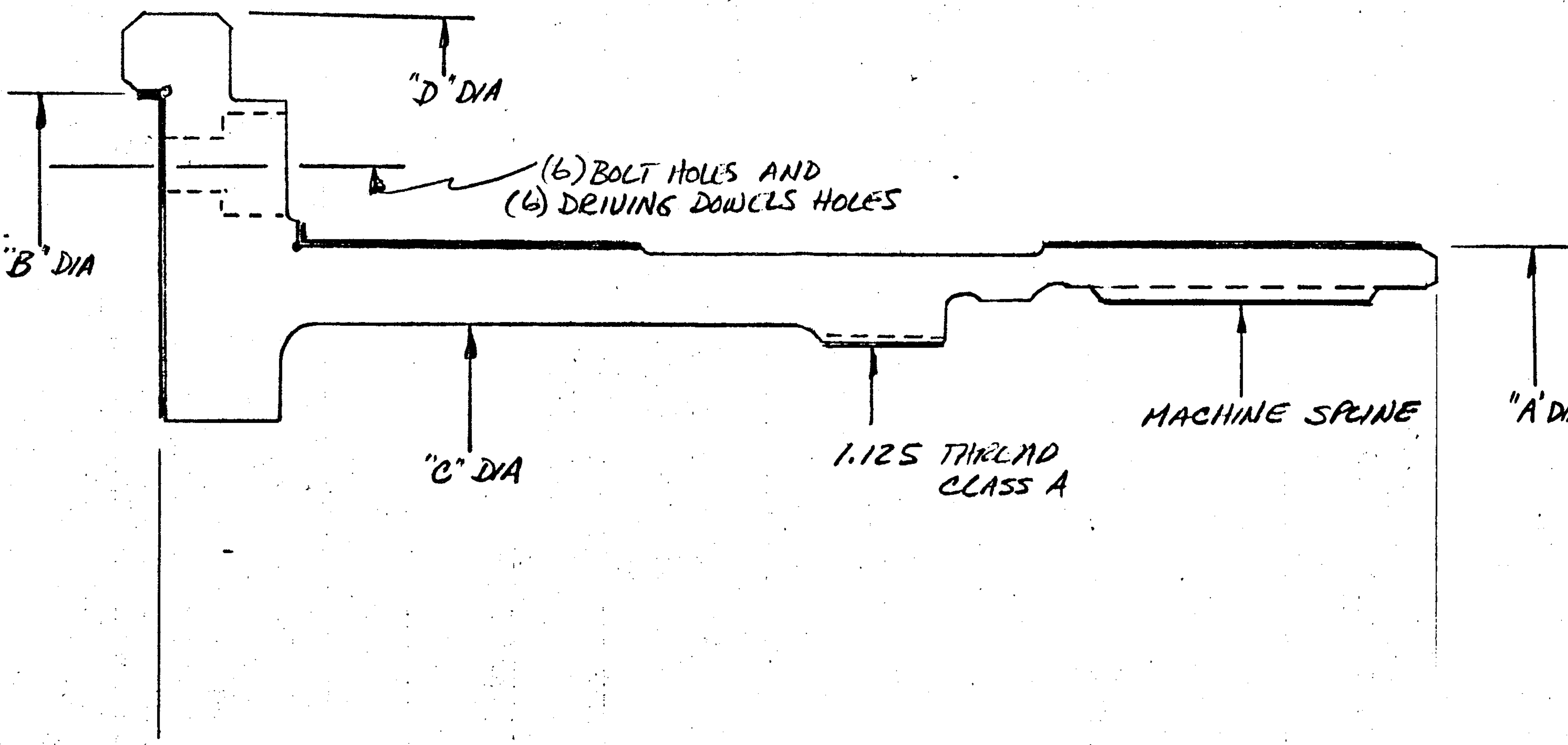
SHEET 1 OF 2

PLANNER: N/C	CUSTOMER REVIEW: DCS / SKN	SERIAL NO.	PART NO.: 1724 #2	CHG LTR: N/C	W.O. PARTS IN STORE: -	QTY	W.O.: 8132
PLANNER: DLE / DATE: 10-14-69	Q.C. APP. / DATE	MATERIAL TYPE AND SIZE: INCONEL "X"	PART NAME: SHAFT / CUSTOMER: AGC / HEAT NO.	E.O. NO.	P.O. NO.: L-109093 / USE MAT'L FROM W.O. / SIZE	QTY / LOT ESB'D / MFG REQ'D / DUE DATE
NEXT ASSY NO.	FINAL ASSY NO.: 1136900					

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND TURN CRITICAL CONTROL DIAMETERS									LAFX	
			AND MACHINED CONFIGURATION (REF SKETCH)									(PIE-JAN)	
	38		DIAMETER	"A"	2.250	±.0005							
	28 HRS		"	"B"	5.000	±.001							
	33		"	"C"	1.250	±.010							
			THREAD		1.125	CL A						THREAD	
			DIAMETER	"D"	6.000	±.010						GAGES	
			HOLD		⊙.001	TIR							
			FINISH		63√								
25	MILL		MACHINE SPLINE (1) PLACE PER B/P (REF SKETCH)									MLFX	
	20 8 HRS												
30	8 DRILL		DRILL (6) BOLT HLS + (6) DOWEL HOLES									DRJ1	
	1 HRS		PER B/P + SKETCH										
	16 8 HRS 8												
40	SHOP		DEBURR COMPLETE		.005	MAX							
	1 HR		+ CLEAN THREADS										

LTR	CHANGE

ITEM #2
SHAFT


"D" DIA
(6) BOLT HOLES AND
(6) DRIVING DOWELS HOLES
"B" DIA
"A" DIA
MACHINE SPLINE
"C" DIA
1.125 THREAD
CLASS A

LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

PLANNER CHG.: N/C	CUSTOMER DEPT REVIEW: SHH	SERIAL NO:	PART NO: ITEM #5
PLANNER: DEE	Q.C. APP.	MATERIAL TYPE AND SIZE: INCONEL "X"	PART NAME: SPACER BEARING
DATE: 10-14-69	DATE		CUSTOMER: AGC
NEXT ASSY NO.		FINAL ASSY NO.: 1136900	NEXT ASSY:

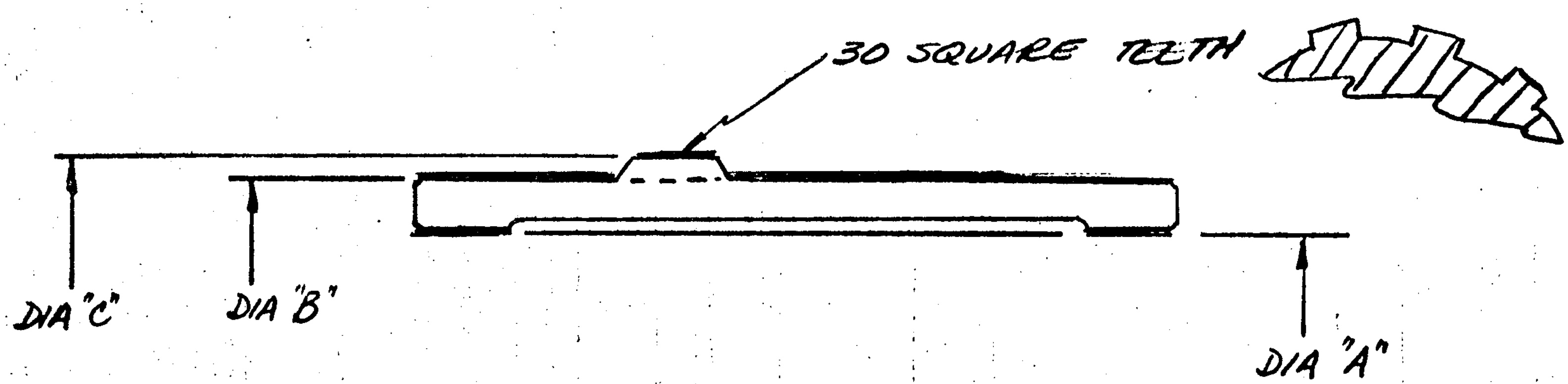
CHG LTR: N/C	W.O. PARTS IN STORE: -	QTY:
E.O. NO.	P.O. NO.: L-109093	QTY:
	USE MAT'L FROM W.O.	SIZE

W.O.	8132
LOT RSQ'D	
MFG REQ'D	
DUE DATE	

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND TURN CRITICAL CONTROL DIAMETERS									PIE JAW	
			AND MACHINED CONFIGURATION (REF SKETCH)										
			DIAMETER "A"		2.249	±0005							
	14 / 12	HRS	"B"		2.875	±005							
	14		"C"		3.250	±002							
			HOLD CONCENTRICITY		⊙.001								
			FINISH		32√ ON DIA A								
			DEBURR COMPLETE		.005	MAX							
30	MILL		MACH (BROACH) (30) SQUARE TEETH & DEBURR										
	1 1/4	HRS											
40	INSP.		INSPECT THRU OPER 30										
50	P/C		STORE FOR N/ASSY										
			OR PREPARE FOR										
			SHIPMENT TO CUSTOMER										

LTR	CHANGE

ITEM #5
SPACER BEARING



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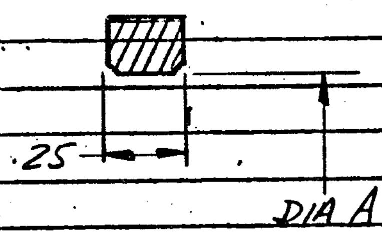
LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

RELEASE CHG. N/C	CUSTOMER DEPT REVIEW SIGN	SERIAL NO.	PART NO. ITEM #3.5	CHG LTR N/C	NO. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE INCONEL "X"	PART NAME UPPER SPACER	E.O. NO.	P.O. NO. L-109093	QTY	LOT SIZE
DATE 10-14-69	DATE		CUSTOMER		USG MAT'L REQN W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.	FINAL ASSY NO. 1136900		NEXT NO.				DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.R.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		MACHINE PER B/P AND SKETCH										
			DIA A		2.750	±.0005							
	$\frac{3}{4}$ 2 HRS				63/								
30	INSP		INSPECT OPER 20										
40	PROCESS		PROCESS PER B/P										
50	P/C		STORE FOR N/ASSY OR PREPARE FOR SHIPMENT TO CUSTOMER										



LTR	CHANGE

LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

PLANNER CHG. N/C	CUSTOMER DATA REVIEW SHN	SERIAL NO.	PART NO. ITEM #6.5	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE INCONEL "X"	PART NAME LOWER SPACER	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	NSAP NO.				DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		MACHINE PER B/P + SKETCH									PIEJAW	
			DIA "A"		2.750	±.0005							
	3/2 HRS 4		WIDTH		.25	±.03							
			FINISH		63								
			 .25 DIA "A"										
30	INSP		INSPECT OPER 20										
40	PROCESS		PROCESS PER B/P										
50	P/C		STORE FOR N/ASSY										
			OR PREPARE FOR										
			SHIPMENT TO CUSTOMER										

LTR	CHANGE

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LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 2

REVISION N/C	CUSTOMER REVIEW DATE / SIGN	SERIAL NO.	PART NO. 1211 # 8	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
CHG.							
PLANNER DCE	Q.C. APP.	MATERIAL TYPE AND SIZE INCONEL "X"	PART NAME TURBINE COUPLING	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.				DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND TURN CRITICAL CONTROL DIAMETERS									LAEX	
			AND MACHINED CONFIGURATION (REF: SKETCH)									(PIE JAW)	
			DIAMETER	"A"	4.000	±001							
	26 21 HRS 26		"	"B"	2.000	±005							
			"	"C"	5.500	±010							
			"	"D"	.750	±0005							
			"	"E"	1.875	±0005							
			SURFACE "X"		⊥ A .0005								
			SURFACE "Y"		⊥ THREADS .001								
			HOLD CONCENTRICITY		⊙ .001 TIR								
			FINISH		32√ ON D & E								
			DEBURR COMPLETE		.005	MAX							
30	DRILL PRESS		USE FIXTURE AND DRILL (6) HOLES									DRJ1	
	4 4 HRS		PER B/P (REF: SKETCH)										
35	MILL		MACHINE (2) SPLINES PER B/P (REF: SKETCH)									HOLDING FIXTURE	
	8 HRS												

LTR	CHANGE

LAMCO INDUSTRIES, INC.

SHEET 2 OF 2

PLANNER CHG	CUSTOMER	PART NAME	PART NO.	CHG LTR	W/O NO.
N/C	AGC	TURBINE COUPLING	ITEM #8	N/C	8132

OPER NO.	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM.	TOL.	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
40	SHOP		DEBURR HOLES		.005	MAX							
			CLEAN THREADS										
	2 2 HRS 2												
50	INSP		INSP THROUGH OPER 40										
60	PROCESS		PROCESS PER B/P										
70	P/C		STORE FOR N/ASSY										
			OR PREPARE FOR										
			SHIPPING TO CUSTOMER										

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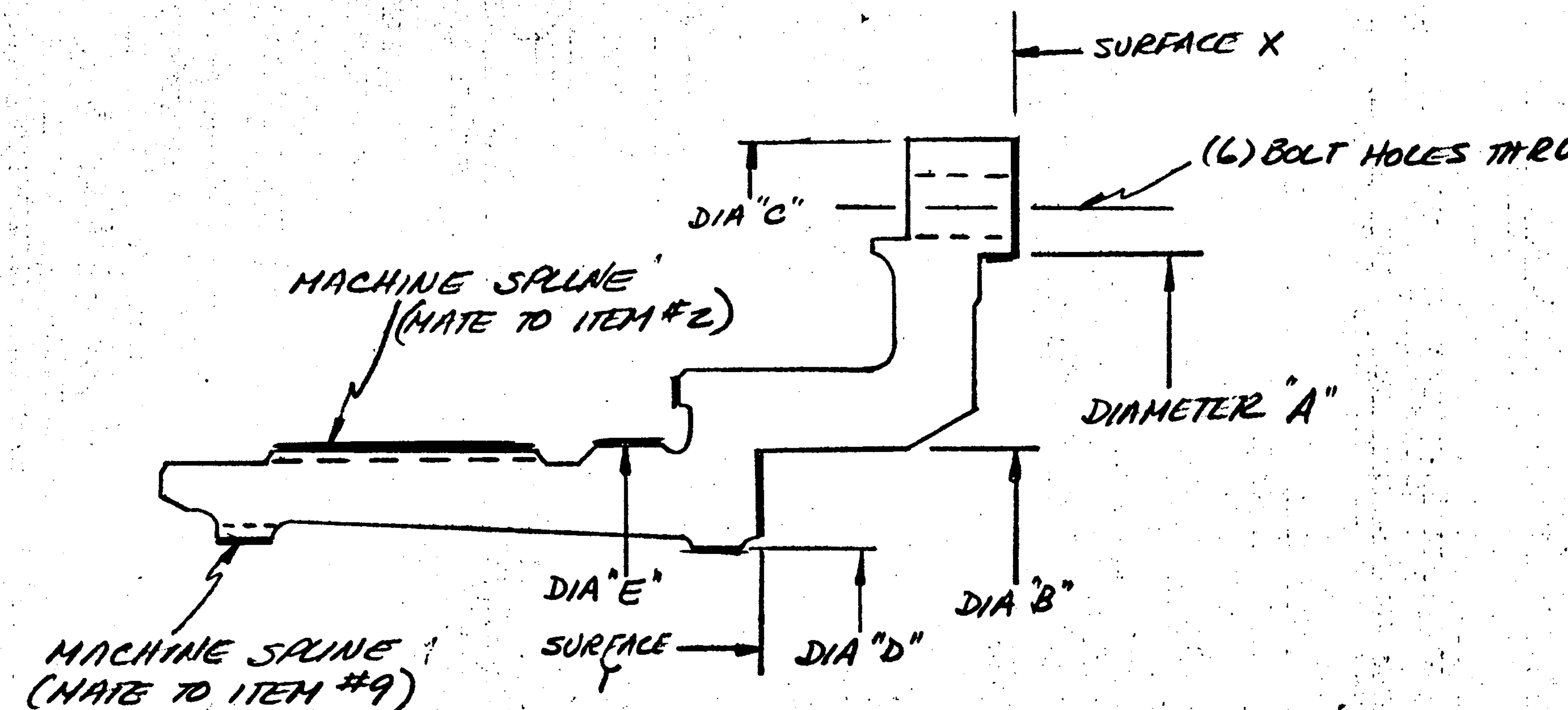
ITEM #8
TURBINE COUPLING



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

PLANNING N/C CHG.	CUSTOMER REVIEW DATE SIGN	SERIAL NO	PART NO ITEM #9
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE INCONEL "X"	PART NAME SHAFT BOLT
DATE 10-14-69	DATE		CUSTOMER AGC
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.

CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.S. 8132
E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
	USE MAT'L FROM W.O.	SIZE	MFG REQ'D
			DUE DATE

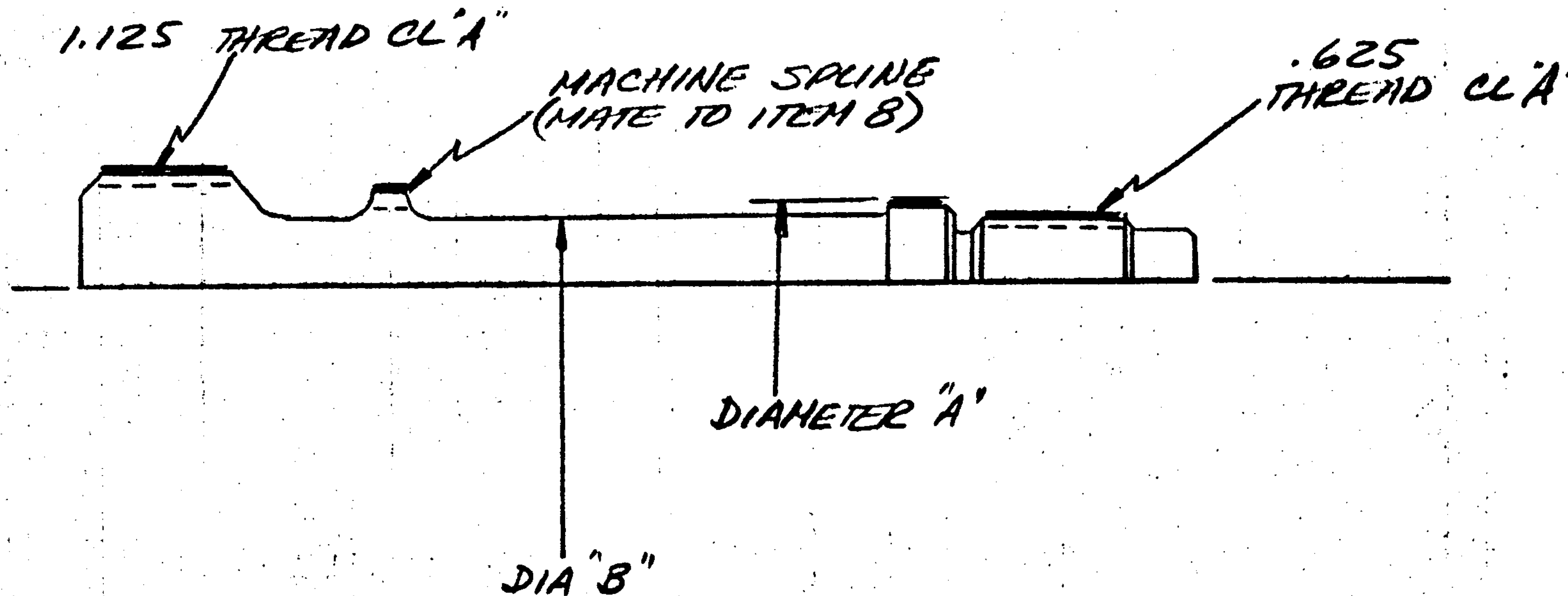
OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACH CRITICAL DIAMETERS, THREADS									(PIEJAW)	
			AND MACH CONFIGURATION PER B/P (REF: SKETCH)										
	11		DIAMETER "A"		.750	±.0005							
	8 HRS		DIAMETER B		.625	±.010							
	16		FINISH		32/	AS NOTED							
			THREAD		.625	CLA							
			HOLD CONCENTRIC		⊙.001 TIR								
			FINISH		63/	UNLESS NOTED							
			DEBURR COMPLETE		.005	MAX							
30	MILL		MACHINE SPLINE PER B/P (REF: SKETCH)									HOLDING FIXTURE	
	4 HRS												
40	10 INSP		INSPECT THRU OPER 30										
50	P/C		STORE FOR N/ASSY										
			OR PREPARE FOR SHIPPING										
			TO CUSTOMER										

LTR	CHANGE

279

19

ITEM #9
SHAFT BOLT



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

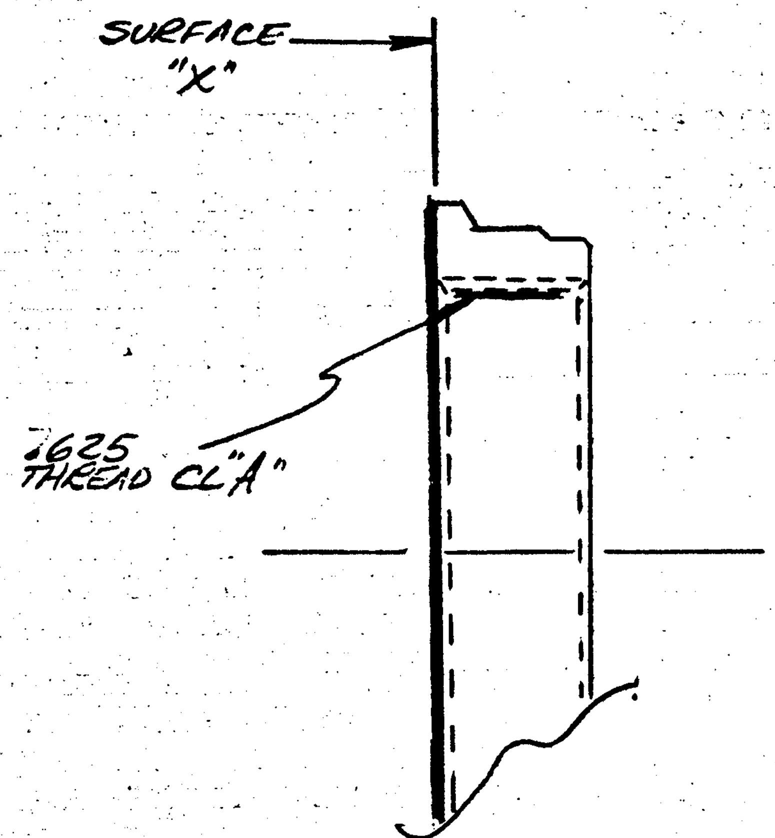
PLANNER CHG. N/C	CUSTOMER DOC REVIEW SEN	SERIAL NO.	PART NO. ITEM #10	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE MAT'L : A286	PART NAME NUT	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.				DUE DATE

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		MACH CONFIGURATION COMP PER B/P									PIC SAW	
			HOLD CRITICAL DIMS (REF: SKETCH)										
			HOLD THREAD		.625	CLA							
	$\frac{7}{1}$ NR		HOLD SURFACE "X"		⊥ A .001								
	4		FINISH		63/								
			DEBURR COMP		.005	MAX							
30	INSP		INSP OPER 20 COMPLETE										
40	PROCESS		PROCESS COMP PER B/P										
50	P/C		STORE FOR N/ASSY										
			OR PREPARE FOR SHIPMENT										
			TO CUSTOMER										

LTR	CHANGE

281

ITEM # 10
NUT



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

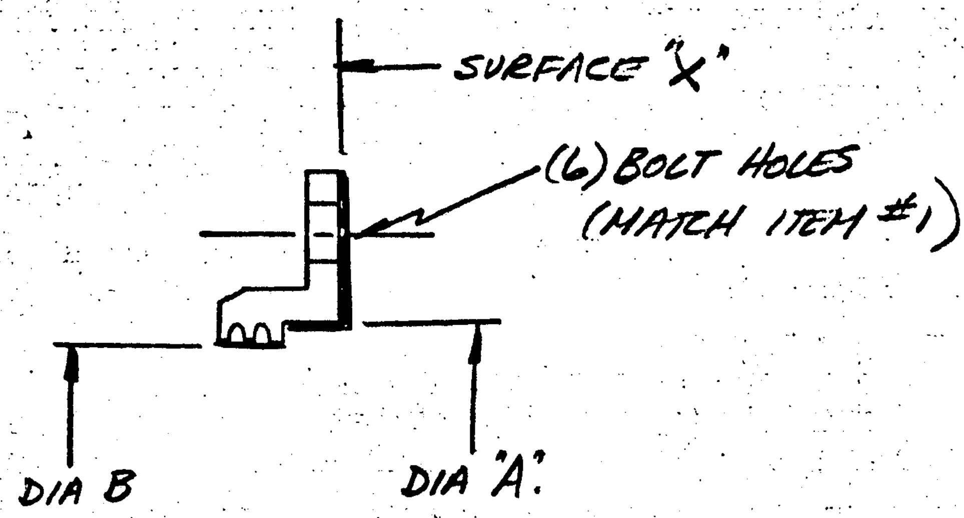
PLANNER CHG. N/C	CUSTOMER REVIEW DATE SIGN	SERIAL NO.	PART NO. ITEM #11	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DEI	Q.C. APP.	MATERIAL TYPE AND SIZE PHOSPHOROUS BRONZE	PART NAME LABYRINTH SHAFT	E.O. NO.	P.O. NO. C-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.	FINAL ASSY NO. 1136900		HEAT NO.				DUE DATE

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACH. CONFIGURATION PER B/P									PIE JAW	
			HOLD CRITICAL DIAMETERS (REF: SKETCH)										
	3 3/4 HRS		DIAMETER "A"		4.500	+.001 -.000							
			" " "B"		4.250	±.001							
			SURFACE "X"		⊥ A .001								
			FINISH		63√								
			DEBURR COMPLETE		.005	MAX							
30	DRILL PRESS		USE DRILL PLATES AND DRILL (6) HOLES TO MATCH ITEM #1									DRJ1	
40	SHOP	1 HR 3	DEBURR HOLES		.005	MAX							
50	INSP		INSP THROUGH OPER 40										
60	PROCESS		PROCESS COMPLETE PER B/P										
70	P/C		STORE FOR N/ASSY OR PREPARE FOR SHIPMENT TO CUSTOMER										

LTR	CHANGE

283

ITEM # 11
LABYRINTH SHAFT



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

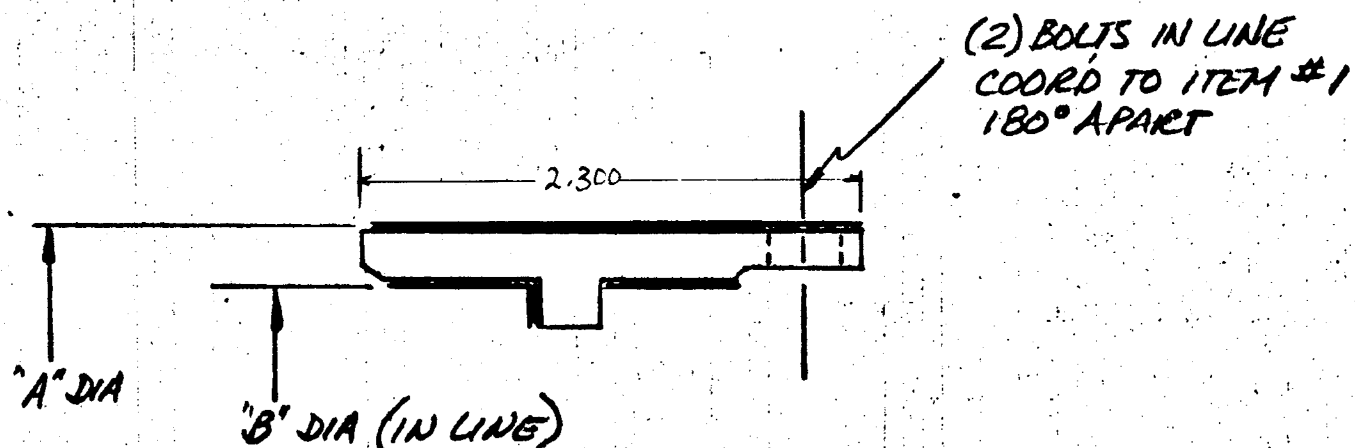
PLANNER CHG. N/C	CUSTOMER REVIEW	SERIAL NO.	PART NO. ITEM #12	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DCE	Q.C. APP.	MATERIAL TYPE AND SIZE INCONEL "X"	PART NAME UPPER BRG CARRIER	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	NEXT NO.				DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		MACHINE COMPLETE PER B/P									PIC SAW	
			TURN CRITICAL DIAMETERS (REF SKETCH)										
			DIAMETER "A"		4.249	+0000 -0005							
	6 HRS		" "B"		3.750	±001							
	10		HOLD CONCENTRIC		⊙.001	TIR							
			FINISH		63/								
			DEBURR COMPLETE		.005	MAX							
30	DRILL PRESS		SCRIP + DRILL (2) HOLES PER SKETCH									DRJ1	
			MUST COORD TO ITEM #1										
	1 HR												
40	SHOP		DEBURR HOLES COMP		.005	MAX							
	1 HR												
50	INSP		INSP THROUGH OPER 40										
60	PROCESS		PROCESS COMPUTER PER B/P										
70	P/C		STORE FOR N/ASSY										

LTR	CHANGE

285

ITEM 12
BEARING CARRIER



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

PLANNER CHG. N/C	CUSTOMER DCJ REVIEW SGN	SERIAL NO	PART NO ITEM # 13	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 813E
PLANNER DCE	Q.C. APP.	MATERIAL TYPE AND SIZE INCO X ~~410 CRES~~	PART NAME LWR BRG CARRIER	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	NFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 113690	NSAP NO.				DUE DATE

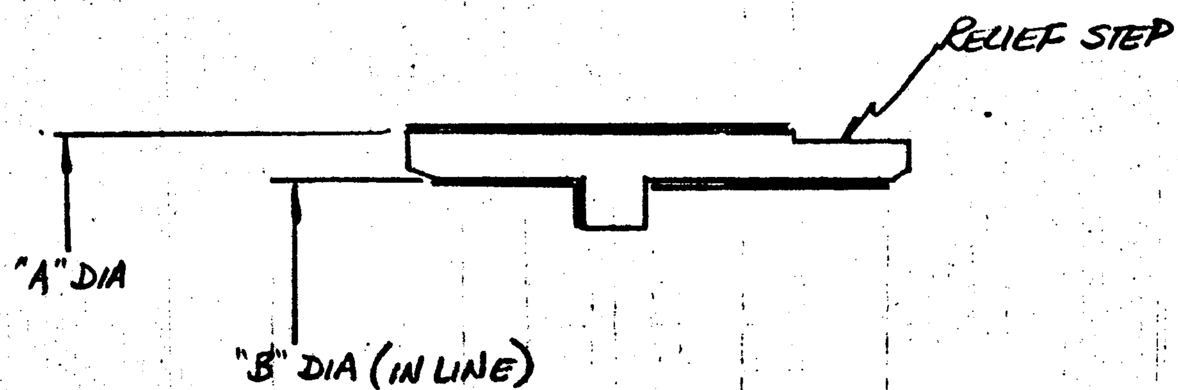
OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	C.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CONFIGURATION									PIE-JAW	
			PER B/P AND SKETCH										
			DIAMETER "A"		4.249	+0000 -0005							
	8.5 7 HRS		" "B"		3.750	±001							
	12		HOLD CONCENTRIC		⊙.001	TIR							
			FINISH		63√								
			DEBURR COMPLETE		.005	MAX							
30	INSP		INSP OPER 20										
40	PROCESS		PROCESS COMPLETE PER B/P										
50	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPMENT										
			TO CUSTOMER										

LTR	CHANGE

287

288

ITEM 13
LOWER BEARING CARRIER



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

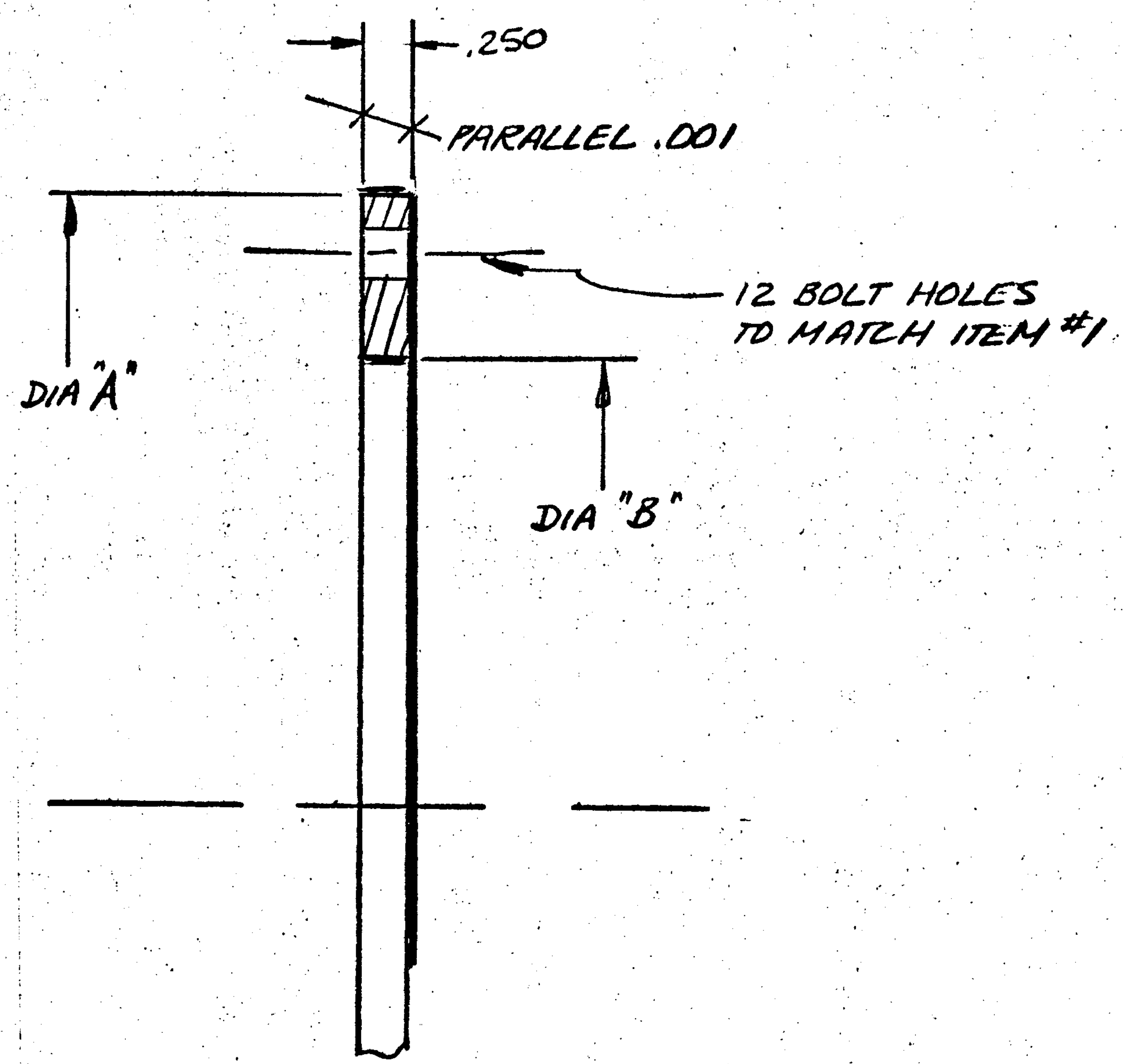
PLANNER CHG. N/C	CUSTOMER DEPT REVIEW SIGN	SERIAL NO.	PART NO. ITEM #15	CHG LTR N/C
PLANNER DCE	Q.C. APP.	MATERIAL TYPE AND SIZE INCONEL "X"	PART NAME SPACER SHIM	E.O. NO.
DATE 10-11-69	DATE		CUSTOMER AGC	
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.	

W.O. PARTS - IN STORE	QTY	W.S. 8132	
P.O. NO. L-109093	QTY	LOT REQ'D	
USE MAT'L FROM W.O.	SIZE	MFG REQ'D	
		DUE DATE	

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE PER B/P									PIE JAW	
			HOLD DIMS (REF: SKETCH)										
			DIAMETER "A"		5.000	±.001							
	2.5 1.5	HR	" "B"		4.000	±.005							
	3.0		PARALLELISM		WITHIN .001								
			FINISH		63/								
			DEBURR COMPLETE		.005	MAX							
30	DRILL		DRILL (12) HOLES (MATCH WITH ITEM #1)									DEJI	
	MACES 1.0	HR											
40	2.5 SHOP		DEBURR HOLES COMP		.005	MAX							
	1.5 .5	HR											
50	INSP		INSPECT THROUGH OPER 40										
60	PROCESS		PROCESS COMPLETE PER B/P										
90	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPMENT										
			TO CUSTOMER										

LTR	CHANGE

ITEM #15
SPACER SHIM



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

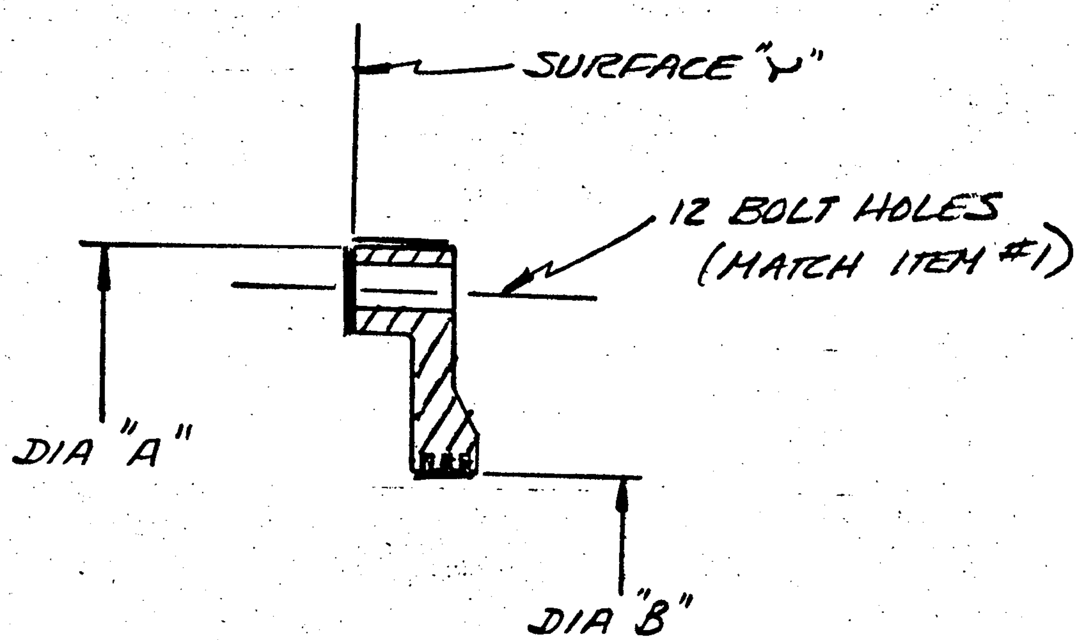
RELEASE N/C CHG.	CUSTOMER EVAL REVIEW SEN	SERIAL NO.	PART NO. ITEM #16	CHG LTR N/C	W.O. PARTS - IN STORE	QTY	W.O. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE PHOSPHOROUS BRONZE	PART NAME LABYRINTH BEARING	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	KSAT NO.				EXP DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CONFIGURATION									(PIE JAW)	
			AND CRITICAL DIAS (REF: SKETCH)										
			DIAMETER "A"		5.000	+.0005							
	4/3 HRS		" "B"		3.000	+.001							
	5		SURFACE "Y"		⊥ A .0005								
			FINISH		63√								
			DEBURR COMPLETE		.005	MAX							
30	DRILL PRESS 1 1/3 HR		DRILL (12) HOLES (MATCH TO ITEM #1)									DRJ1	
40	INSP		INSP COMP PER OPER 20 & 30										
50	PROCESS		PROCESS COMP PER B/P										
60	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPMENT										
			TO CUSTOMER										

LTR	CHANGE

291

ITEM #16
LABYRINTH BEARING



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

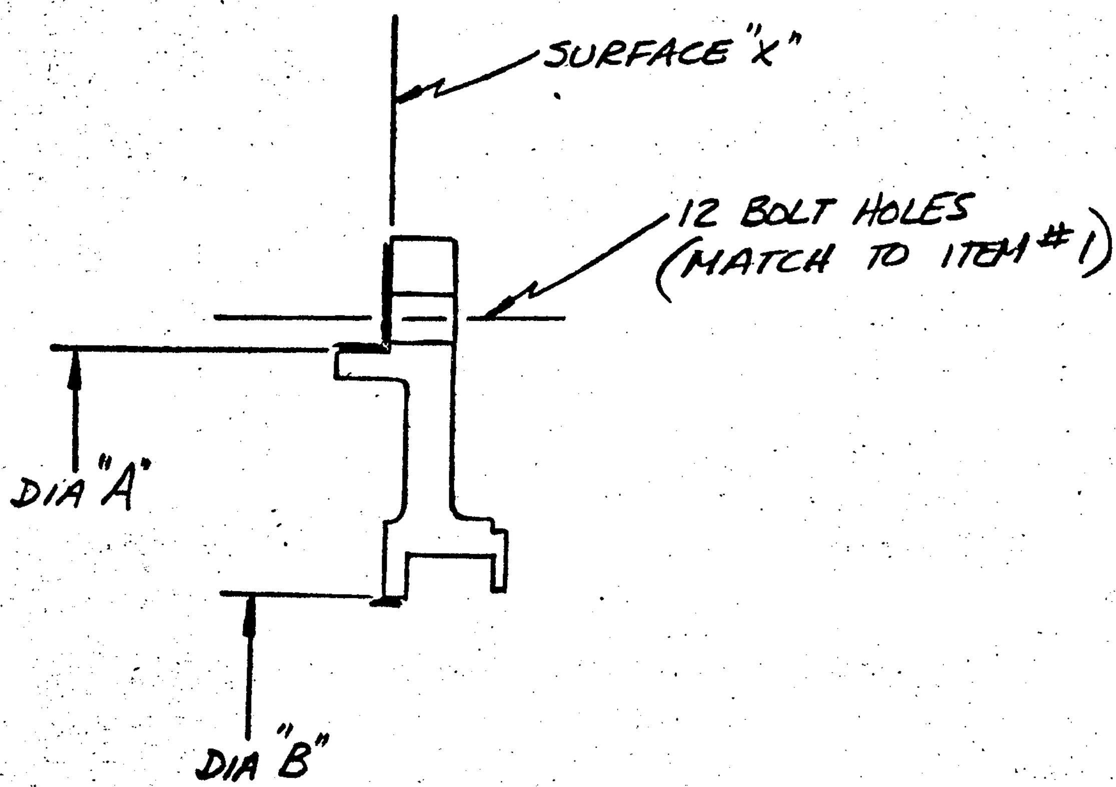
PLANNER CHG. N/C	CUSTOMER REVIEW	SERIAL NO.	PART NO. ITEM #17	W.O. PARTS IN STORE	W.J. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE SEE B/P	PART NAME SEAL ASSY	P.O. NO. L-109093	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC	USE MAT'L FROM W.O.	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.		DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CONFIGURATION									LAFX	
			PER B/P (REF: SKETCH)									(PIE SAW)	
			DIAMETER "A"		5.625	±010							
	13 11 HRS 19		" "B"		3.000	±010							
			SURFACE "X"		⊥ A .001								
			FINISH		63								
			DEBURR COMPLETE		.005	MAX							
30	DRILL PRESS		DRILL (12) HOLES (MATCH TO ITEM #1)									DRJI	
	3/2 HRS												
40	INSP		INSPECT THROUGH OPER 30										
50	PROCESS		PROCESS PER B/P										
60	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPMENT										
			TO CUSTOMER										

LTR	CHANGE

293

ITEM #17
SEAL ASSY



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

PLANNER CHG. N/C	CUSTOMER REVIEW SIGN	SERIAL NO.	PART NO. ITEM #20	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE INCONEL 718	PART NAME BOLT	E.O. NO.	P.O. NO. L-109093	QTY 6EA	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.				DUE DATE

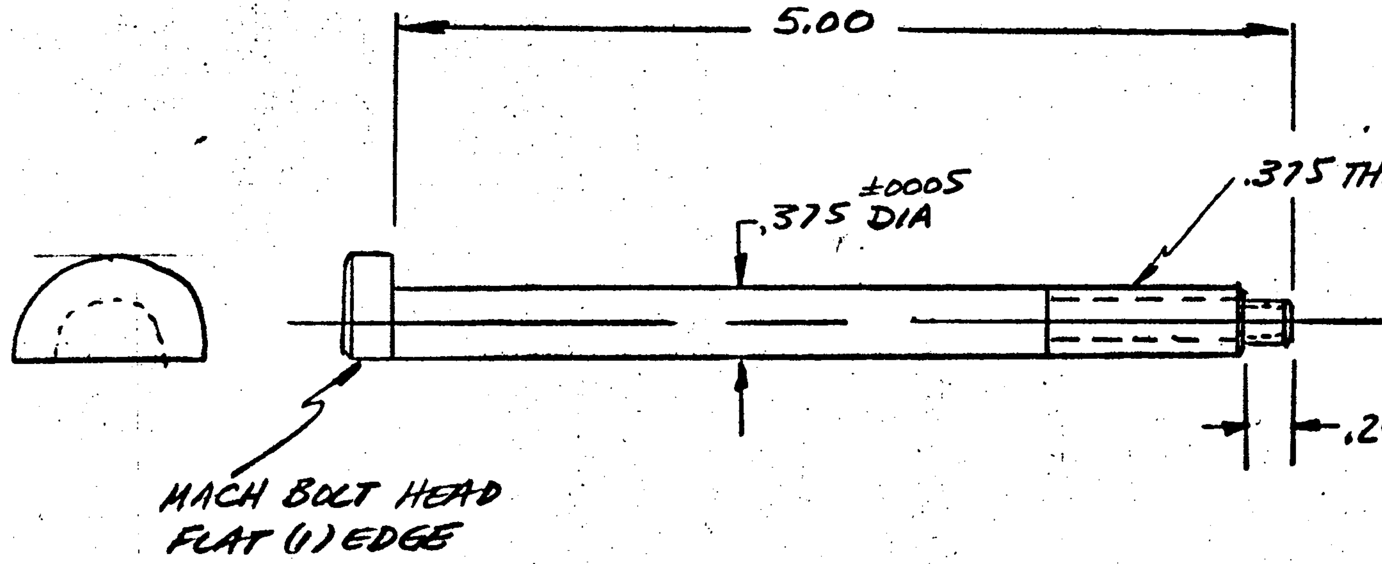
OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		MACHINE CRITICAL BOLT PER B/P									PIEJAW	
			(REF: SKETCH)										
	6 HRS		DIAMETER		.3750	±.0005							
	11		THREAD		.375	CLASS A							
			HOLD		⊙ .001	TIR							
			FINISH (SHANK)		32								
			DEBURR		.005	MAX							
30	MILL		MACH BOLT HEAD - OFFSET (1) PLACE										
	1.5 HRS												
40	INSP		INSPECT THROUGH OPER 30										
50	PROCESS		PROCESS PER B/P										
60	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPMENT TO										
			CUSTOMER										

LTR	CHANGE

295

296

ITEM #20
BOLT



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

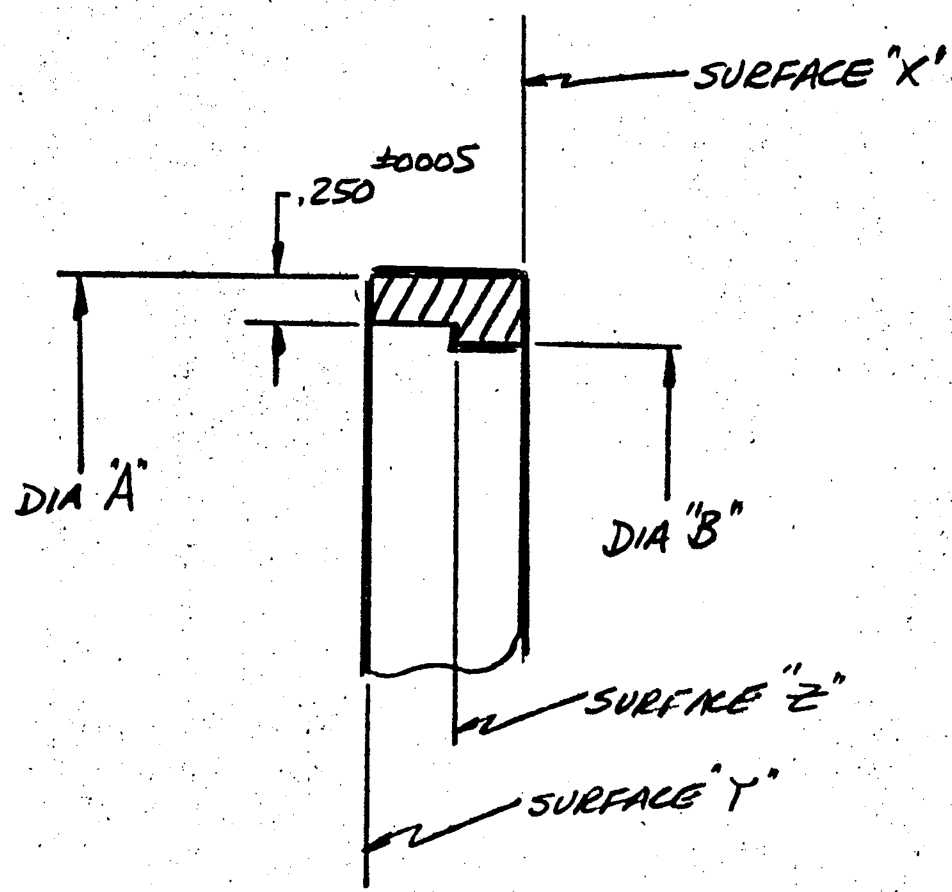
PLANNING CHG. N/C	CUSTOMER REVIEW DOC'T SKN	SERIAL NO	ASSY NO ITEM #22
CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DCZ	Q.C. REP.	MATERIAL TYPE AND SIZE INCONEL 718	PART NAME LWR ORFICE RING
E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-19-67	DATE		CUSTOMER AGC
USE MAT'L FROM W.O.	SIZE		MFG REQ'D
NEXT ASSY NO.	FINAL ASSY NO. 1136900	HEAT NO.	DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND TURN CRITICAL CONTROL DIAS AND MACHINE B/P CONFIGURATION (REF: SKETCH)									PIG JAW	
			DIAMETER "A"		7.000	+.000 -.001							
	5.0 3.5 HRS 10.0		" "B"		6.500	±005							
			SURFACE "Y"		⊥ A .001								
			THICKNESS		.250	±0005							
			FINISH		16√ ON "Y"								
			SURFACE "X"		FLAT .001								
			SURFACE "Z" & "X" PARALLEL TO "Y" WITHIN .001										
30	INSP		INSPECT OPER 20										
40	PROCESS		PROCESS PER B/P										
50	P/C		STORE FOR N/ASSY OR PREPARE FOR SHIPMENT TO CUSTOMER										

LTR	CHANGE

297

ITEM # 22
ORFICE RING (LOWER)



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

CHS. N/C	CUSTOMER REVIEW	SERIAL NO.	ITEM #23	CHG LTR N/C	W.O. PARTS IN STORE -
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE 347 CRES	PART NAME ORFICE RING NUT	E.O. NO.	P.O. NO. L-109093
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O. / SIZE
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.		

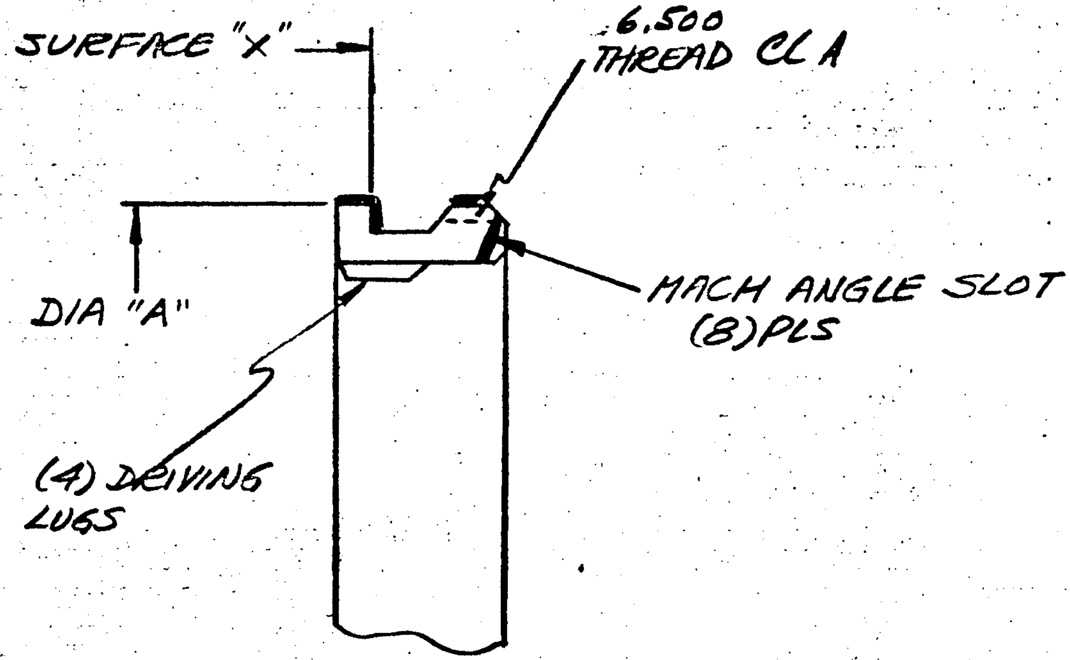
QTY: | W.J. 8132 | LOT CERT'D | NFG REQ'D | EXP DATE

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CRITICAL DIAMETERS									(PIESAW)	
			PER B/P CONFIGURATION (REF: SKETCH)										
		4.5	DIAMETER "A"		6.750	±0005							
		3.0 HR	THREAD		6.500	CL A							
		6.5	SURFACE "X"		⊥ A .001								
			FINISH		63√								
30	MILL	1.5 1.5 HR	MACHINE ANGLE SURFACES (8) PLS									MLFX	
35	MILL	1.0 1.0 HR	MACHINE (4) DRIVING LUGS (REF SKETCH										
40	SHOP	.5 .5 HR .5	DEBURR COMPLETE		.005	MAX							
50	INSP		INSPECT THROUGH OPER 40										
60	PROCESS		PROCESS COMPLETE PER B/P REQ'MENTS										
70	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPMENT TO CUSTOMER										

LTR	CHANGE

667

ITEM # 23
ORFICE RING NUT



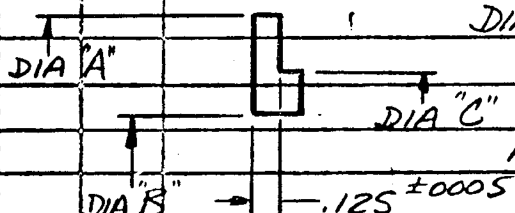
LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELLER AND INSPECTION LOG

SHEET 1 OF 1

PLANNING CHG. N/C	CUSTOMER REVIEW	DATE / SIGN	SERIAL NO	PART NO: ITEM # 27	CHG LTR: N/C	W.O. PARTS IN STORE: – / QTY / W.O. 8132
PLANNER: DEE	Q.C. APP	MATERIAL TYPE AND SIZE: INCONEL 718		PART NAME: ORFICE RING	E.O. NO.	P.O. NO. L-109093 / QTY / LOT REQ'D
DATE 10-14-69	DATE			CUSTOMER: AGC		USE MAT'L FROM W.O. / SIZE / MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900		NEXT NO.		DUE DATE

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CRITICAL DIAMETERS									(PIE JAW)	
			AND CONFIGURATION PER B/P (REF: SKETCH BELOW)										
			DIAMETER "A"		16.000	±001							
			"B"		14.750	±0005							
			"C"		15.250	±001							
			FINISH		63								
			DEBURR		.005	MAX							
8 / 6 / 12	HRS												
30	INSP		INSPECT OPER 20										
40	PROCES		PROCESS PER B/P										
50	P/C		STORE FOR N/ASSY OR PREPARE FOR SHIPMENT TO CUSTOMER										



LTR	CHANGE

301

302

LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

PLANNER CNG. N/C	CUSTOMER DCT REVIEW SIGN	SERIAL NO.	PART NO. ITEM #28	CNG LTR N/C
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE 347 CRES	PART NAME ORFICE RING NUT	E.O. NO.
DATE 10-14-69	DATE		CUSTOMER AGC	
NEXT ASSY NO.	FINAL ASSY NO. 1136900		HEAT NO.	

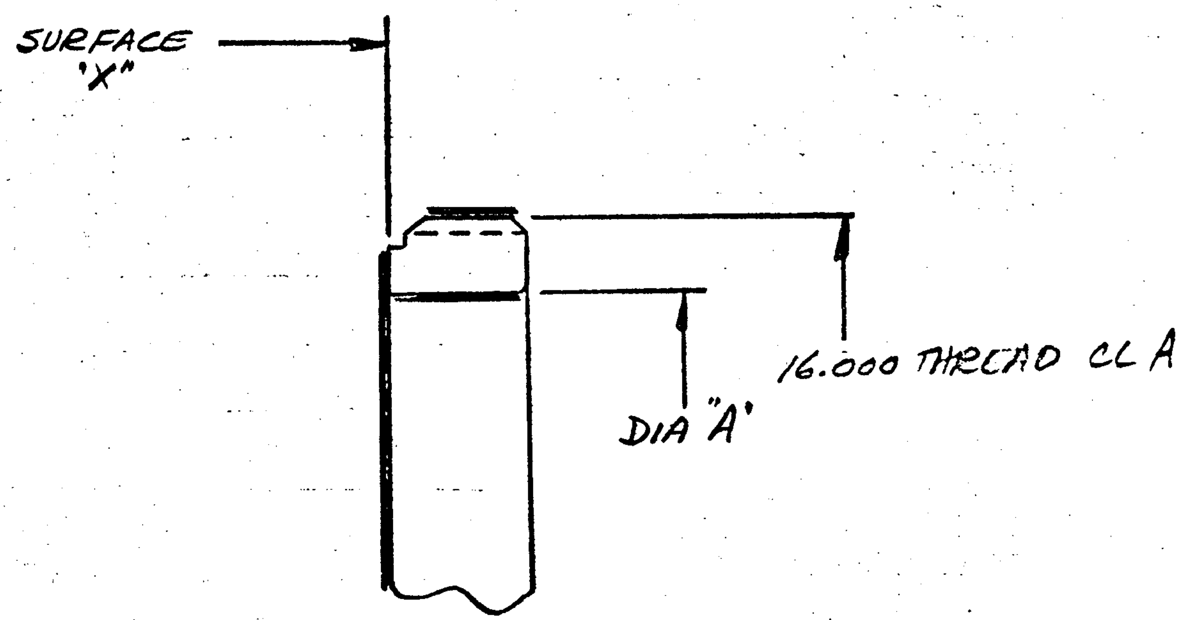
W.O. PARTS IN STORE -	QTY	W.O. 8132
P.O. NO. C-109093	QTY	LOT REQ'D
USE MAT'L FROM W.O.	SIZE	MFG REQ'D
		DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CRITICAL DIMS									(PIE JAW)	
			AND CONFIGURATION PER B/P (REF: SKETCH)										
	12		DIAMETER "A"		15.000	±.0005							
	10 HRS		THREAD		16.000	CL A							
	20		SURFACE "X"		⊥ A .001								
			FINISH		63/								
			DEBURR		.005	MAX							
30	INSP		INSPECT OPER 20										
40	PROCESS		PROCESS PER B/P										
50	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPMENT										
			TO CUSTOMER										

LTR	CHANGE

FORM NO. F-9

ITEM #28
ORFICE RING NUT



304

LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 2

PLANNER CMS.: N/C	CUSTOMER REVIEW: DATE / SIGN	SERIAL NO.	PART NO.: ITEM #29
PLANNER: DEE	Q.C. APP.	MATERIAL TYPE AND SIZE: 347 CRES	PART NAME: VANE HOUSING
DATE: 10-14-69	DATE		CUSTOMER: AEC
NEXT ASSY NO.		FINAL ASSY NO.: 1136900	HEAT NO.

CHG LTR	W.O. PARTS IN STORE: -	QTY	W.S.: 8132
E.O. NO.	P.O. NO.: L-109093	QTY	LOT REQ'D
	USG MAT'L FROM W.O.	SIZE	MFG REQ'D
			DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CRITICAL DIMS									LAEX	
			AND CONFIGURATION PER B/P (REF: SKETCH)									(PIE JAW)	
			HOLD DIAMETER "A"		15.000	±.0005							
			" "B"		15.500	±.005							
	23 15 HRS		" "C"		18.000	±.005							
	23		THREAD		16.000	CL A							
			SURFACE "X"		⊥ A .001								
			MACH POCKET FOR BOLTS (SEE SKETCH)										
			DEBURR		.005	MAX							
30	MILL 40 HRS		SETUP AND PROFILE VANES PER SECTION A-A									PFFX	
40	68 DRILL PRESS 4		DRILL (24) HOLES (TO MATCH ITEM #1)									DRJI	
	3 HRS												
50	10 SHOP		DEBURR COMPLETE		.005	MAX							
	3 2 HRS 3		DO NOT MAR 63 FINISHES										

LTR	CHANGE

7.0

FORM NO. 5-3

LAMCO INDUSTRIES, INC.

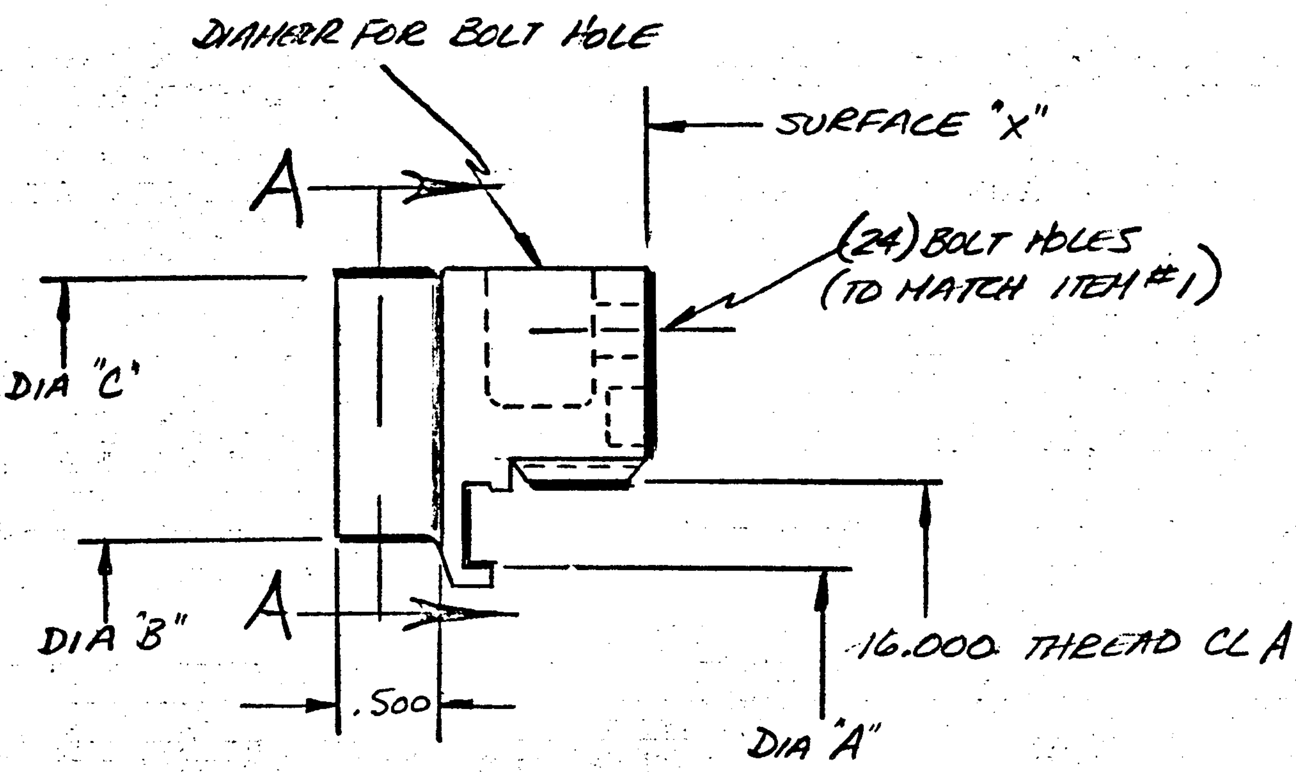
SHEET 2 OF 2

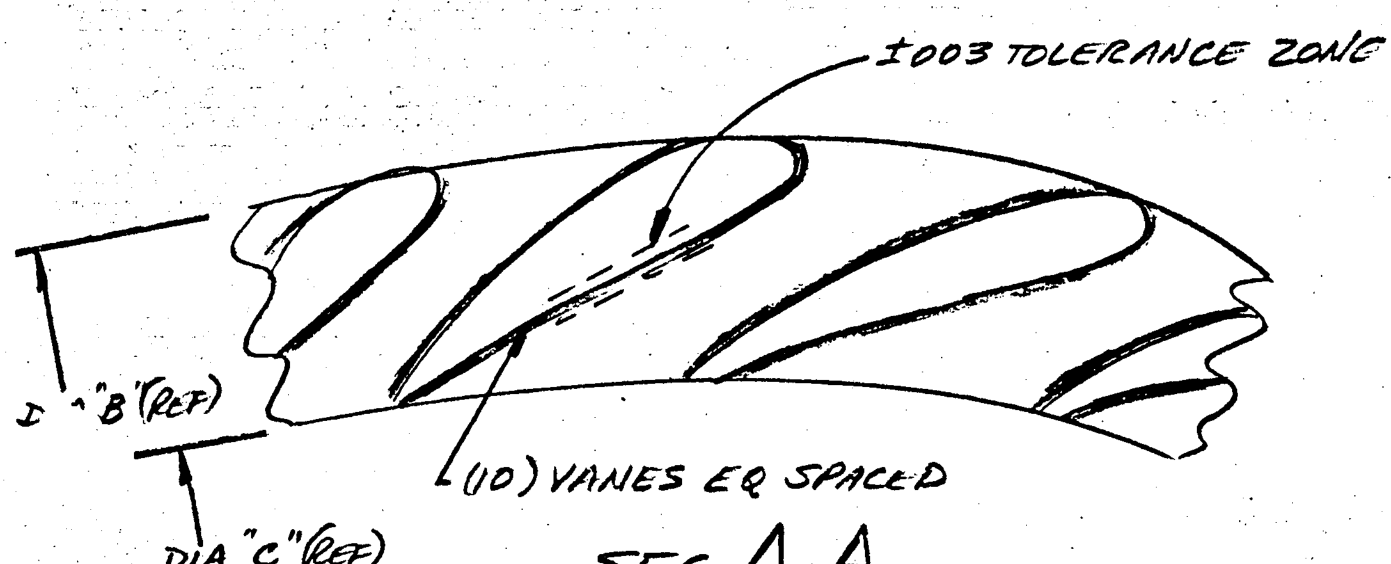
PLANNER CHG	CUSTOMER	PART NAME	PART NO.	CHG LTR	W/O NO.
N/C	AGC	VANE HOUSING	ITEM #29	N/C	8132

OPER NO.	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM.	TOL.	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
60	INSP		INSPECT THROUGH OPER #50										
70	PROCESS		PROCESS PART PER B/P										
80	P/C		STORE FOR N/ASSY OR PREPARE FOR SHIPMENT TO CUSTOMER										

FORM NO. 5-3

ITEM #29
VANE HOUSING





SEC A-A

LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 1

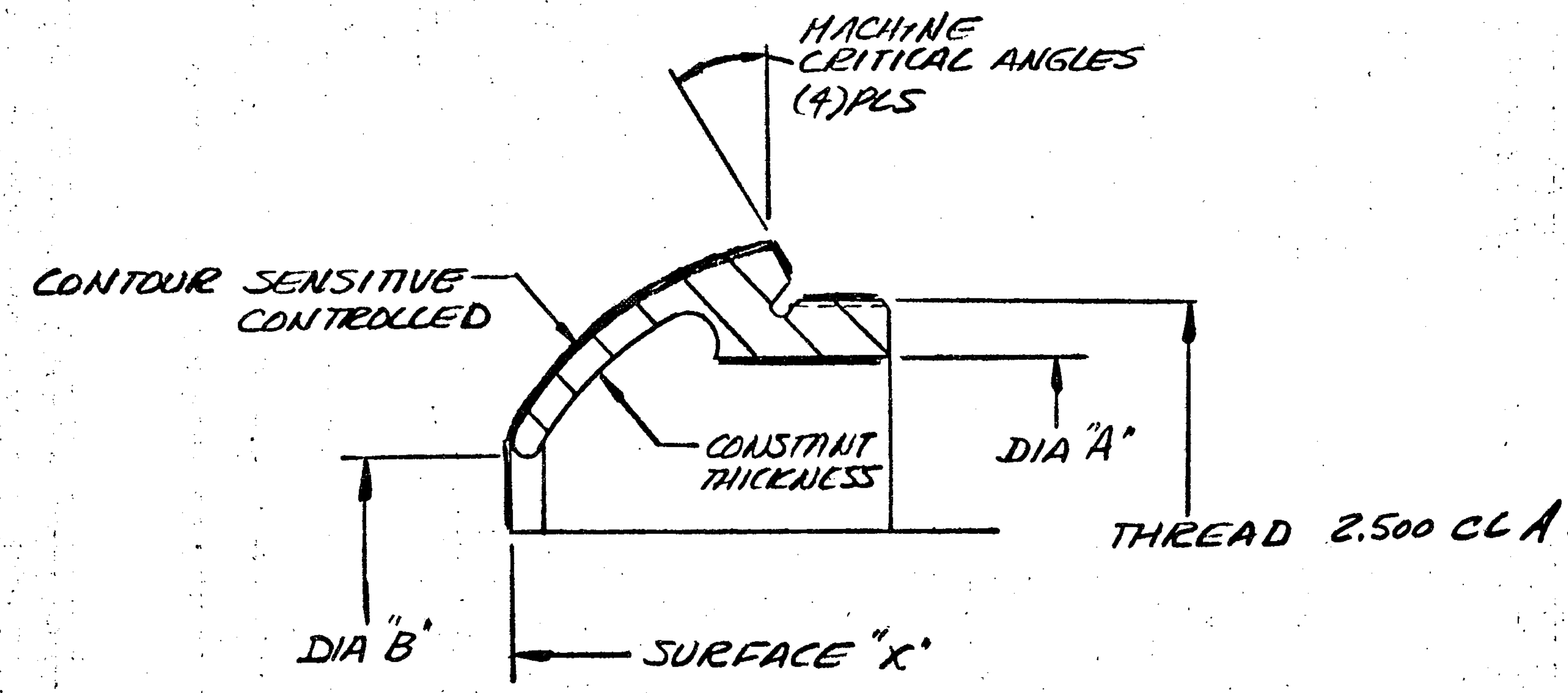
PLANNING CHG. N/C	CUSTOMER REVIEW DATE SIGN	SERIAL NO.	PART NO. ITEM #32	CHG LTR N/C	W.O. PARTS IN STORE -	QTY	W.O. 8132
PLANNER DEE	Q.C. APP	MATERIAL TYPE AND SIZE ALUMINUM	PART NAME ALUM NUT	E.O. NO.	P.O. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O.	SIZE	MFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.				DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CRITICAL DIMS									LAFX	
			PER B/P (REF: SKETCH)									(PIE JAW)	
			DIAMETER "A"		2.000	±001						TCTP	
	4.5 3.5 HRS		" "B"		.750	±001							
	7.0		THREAD		2.500	CL "A"							
			SURFACE "X"		⊥ A .001								
			CONTOUR CONTROL AREA A		LOFT								
			CONSTANT THK'NESS		.125	±002							
			CRITICAL ANGLE		20°	±5'							
			FINISH		63								
30	MILL		MACH. CRITICAL ANGLE (4) PCS										
	1.0 .5 HR												
40	2.0 INSP		INSP THRU OPER 30										
50	P/C		STORE FOR N/ASSY OR PREPARE										
			FOR SHIPMENT TO CUSTOMER										

LTR	CHANGE

307

ITEM #32
ALUM NUT



LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 2

REVISION N/C CHG.	CUSTOMER EXVIEW SIGN	SERIAL NO.	PART NO. ITEM #33	CHG LTR N/C	W.O. PARTS IN STORE - / QTY / W.O. 8132
PLANNER DCE	Q.C. APP	MATERIAL TYPE AND SIZE INCONEL 718 CASTING AND WELDMENT	PART NAME MANIFOLD ASSY	E.O. NO.	P.O. NO. L-109093 / QTY / LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC		USE MAT'L FROM W.O. / SIZE / NFG REQ'D
NEXT ASSY NO.		FINAL ASSY NO. 1136900	HEAT NO.		DUE DATE

OPER NO	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
15	WELD		PREPARE & WELD DETAILS PER B/P (AS REQ'D)										
	1.25 HRS												
20	LATHE		SETUP AND MACHINE CRITICAL DIMS									CAFX	
			AND CONFIGURATION PER B/P (REF: SKETCH)									(PIE JAW)	
			GROOVE "A"		1.000	±.0005 (IF REQ'D)							
	35 25 HRS		DIAMETER "B"		8.500	±.001							
	55		" "D"		14.750	±.001							
			" "E"		12.750	±.001							
			" "F"		16.500	+.000 -.001							
			HOLD CONCENTRIC		⊙.001 TIR								
			FINISH		63								
30	MILL		SETUP AND MACHINE									MILF	
	4 2 HRS		SURFACE -X-		⊥ A .001								
40	JIGBORE		SETUP AND BORE "C"		3.500	±.001						HOLDING (HOFX)	
	2 HRS											FIXTURE	
45	JIGBORE		SETUP AND BORE INLET ADAPTER HOLES									HOFX	
	15 HRS		(5) PLS										

LTR CHANGE

309

LAMCO INDUSTRIES, INC.

SHEET 2 OF 2

PLANNER CHG	CUSTOMER	PART NAME	PART NO.	CHG LTR	W/O NO.
N/C	AGC	MANIFOLD ASSY	ITEM #33	N/C	8132

OPER NO.	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM.	TOL.	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
50	DRILL PRESS		DRILL (48) BOLT HOLES (MATCH TO ITEM #1) @ DIA "F"									DRJI	
			DRILL (36) BOLT HOLES @ DIA "D"									DRJI	
		30 36 60 HRS	DRILL (36) BOLT HOLES @ DIA "E"										
60	SHOP	4 4 4 HR	DEBURR COMPLETELY.		.005	MAX							
70	INSP		INSPECT THROUGH OPER 60										
80	PROCESS		PROCESS COMP PER B/P										
90	P/C		STORE FOR N/ASSY OR PREPARE TO SHIP TO CUSTOMER										

PICCO INDUSTRIES
1729 CHICO AVENUE
SOUTH EL MONTE, CALIFORNIA 91733
(213) 283-7246

A TELEDYNE COMPANY

INVESTMENT CASTINGS
FERROUS AND NON-FERROUS

QUOTATION

Aerojet General
P.O. Box 15847
Sacramento, California

QUOTE NO 12152

DATE 9/16/69

ATTENTION: Mr. A. G. Work, Dept. 96-74, Bldg. 20-25

IN REPLY TO YOUR INQUIRY: DATED:

PART NO.: 1136900 (turbine manifold)

MATERIAL: 718

CONDITION: Sol. Anneal

GRADE: "NASA"

TOOLING: $15,000.00

PRICES:

QUANTITY	PRICE	QUANTITY	PRICE	QUANTITY	PRICE
1 Pc.	$6,000.00	10 Pcs.	$2,000.00	40 Pcs.	$1,700.00

DELIVERY:

DIMENSIONAL SAMPLE 22 WEEKS AFTER RECEIPT OF ORDER.

FIRST PRODUCTION RUN 14 WEEKS AFTER APPROVAL OF DIMENSIONAL SAMPLE

REPEAT ORDER 16 WEEKS AFTER RECEIPT OF ORDER.

SPECIAL CONDITIONS:

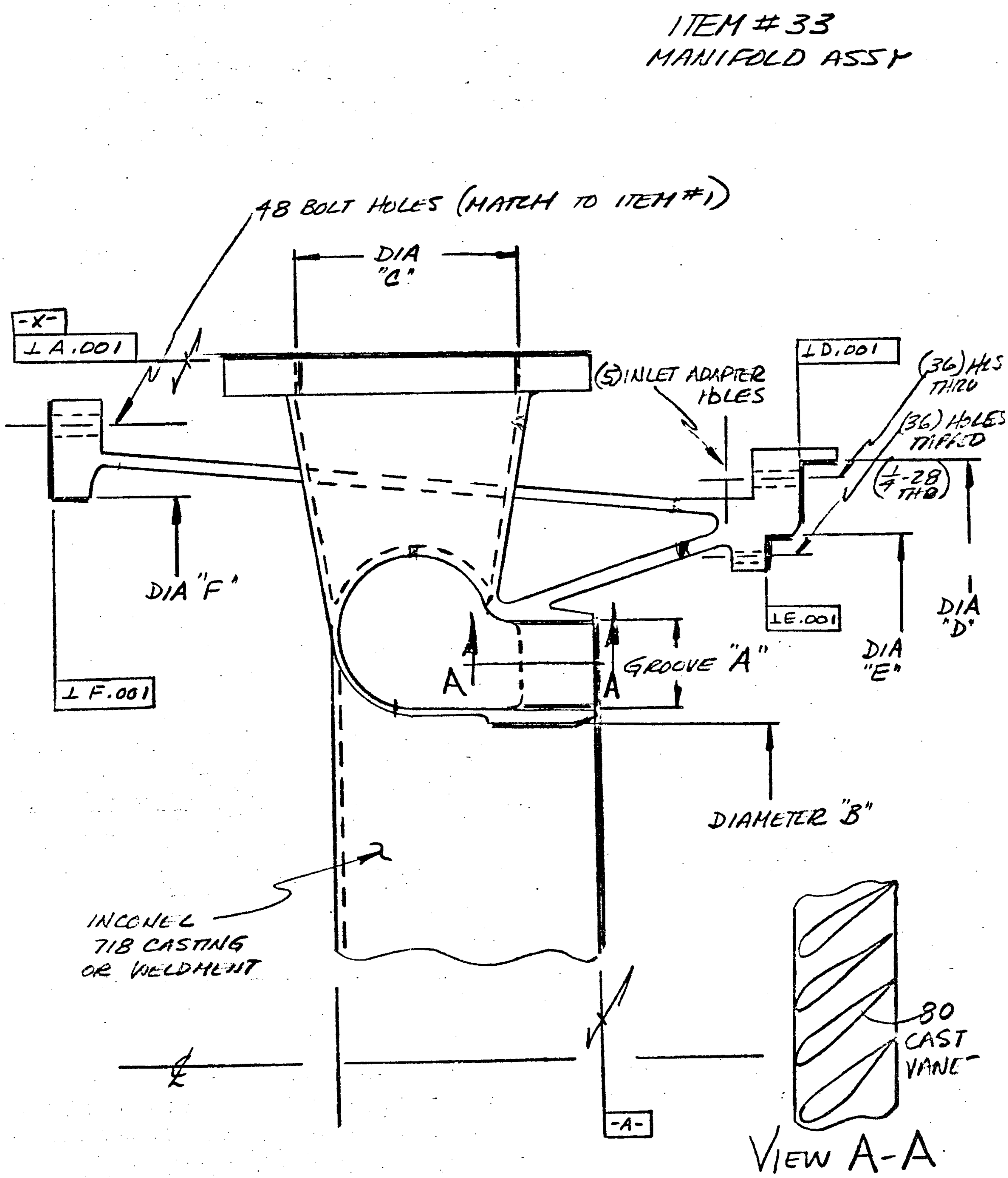
1. THREE (3) COPIES OF PRINTS REQUIRED WITH ORDER.
2. ONE HUNDRED DOLLAR ($100.00) MINIMUM SHIPMENT
3. Subject to review upon receipt of final drawings.

TERMS:

TOOLING: NET AND DUE PRIOR TO PRODUCTION.
CASTINGS: ½% 10 DAYS: NET 30 DAYS.
F. O. B.: SOUTH EL MONTE, CALIFORNIA

BY: DICK HERMES
DIVISION SALES ~~XXXXX~~

R. Hermes


ITEM #33
MANIFOLD ASSY
48 BOLT HOLES (MATCH TO ITEM #1)
DIA "C"
-X-
⊥ A.001
(5) INLET ADAPTER HOLES
⊥ D.001
(36) HLS THRU
(36) HOLES TAPPED
(1/4-28 THD)
DIA "F"
⊥ E.001
DIA "D"
DIA "E"
GROOVE "A"
A
A
⊥ F.001
DIAMETER "B"
INCONEL 718 CASTING OR WELDMENT
80 CAST VANE
-A-
VIEW A-A

LAMCO INDUSTRIES, INC.

PRODUCTION TRAVELER AND INSPECTION LOG

SHEET 1 OF 2

ISSUE N/C CHG.	CUSTOMER DES REVIEW SUN	SERIAL NO	PART NO. ITEM #34
CHG LTR N/C	W.O. PARTS - IN STORE	QTY	W.O. 8132
PLANNER DEE	Q.C. APP.	MATERIAL TYPE AND SIZE 347 CRES CASTING	PART NAME TURBOPUMP HOUSING
E.O. NO.	PO. NO. L-109093	QTY	LOT REQ'D
DATE 10-14-69	DATE		CUSTOMER AGC
USE MAT'L FROM W.O.	SIZE		MFG REQ'D
NEXT ASSY NO.	FINAL ASSY NO.	NEXT ASSY NO.	EXP DATE

OPER No	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM	TOL	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
10	REC		VERIFY MAT'L										
20	LATHE		SETUP AND MACHINE CRITICAL DIMS AND									LAFX	
			CONFIGURATION PER B/P (REF: SKETCH)									(PIEJAW)	
		25	DIAMETER "A"		23.000	+.000 -.001							
		15 HRS	SURFACE "X"		⊥A.001								
		31	DIAMETER "C"		8.500	±.001							
			SURFACE "Z"		⊥C.001								
			FINISH		63/								
25	LATHE	18 10 HRS	SETUP & TRACE CONTOUR (SKETCH) 32/ FINISH									TCTP + PIEJAW	
30	MILL	3	SETUP & MACHINE SURFACE "Y"									MLFX	
		4 4 HRS 10	HOLD		⊥X.001								
40	JIG BORE		SETUP AND BORE DIA "B"		1.500	±.0005						HOLD FIXTURE	
		4 2 HRS 8	(2) PLS HOLD		⊥Y.001							(HOFX)	
			180° APART										
45	DRILL PRESS	3 2 HRS	DRILL (4) BOLT HOLE PATTERN (2) PLS 180° APART									DRPE	

LTR CHANGE 3

313

FORM NO F-2

314

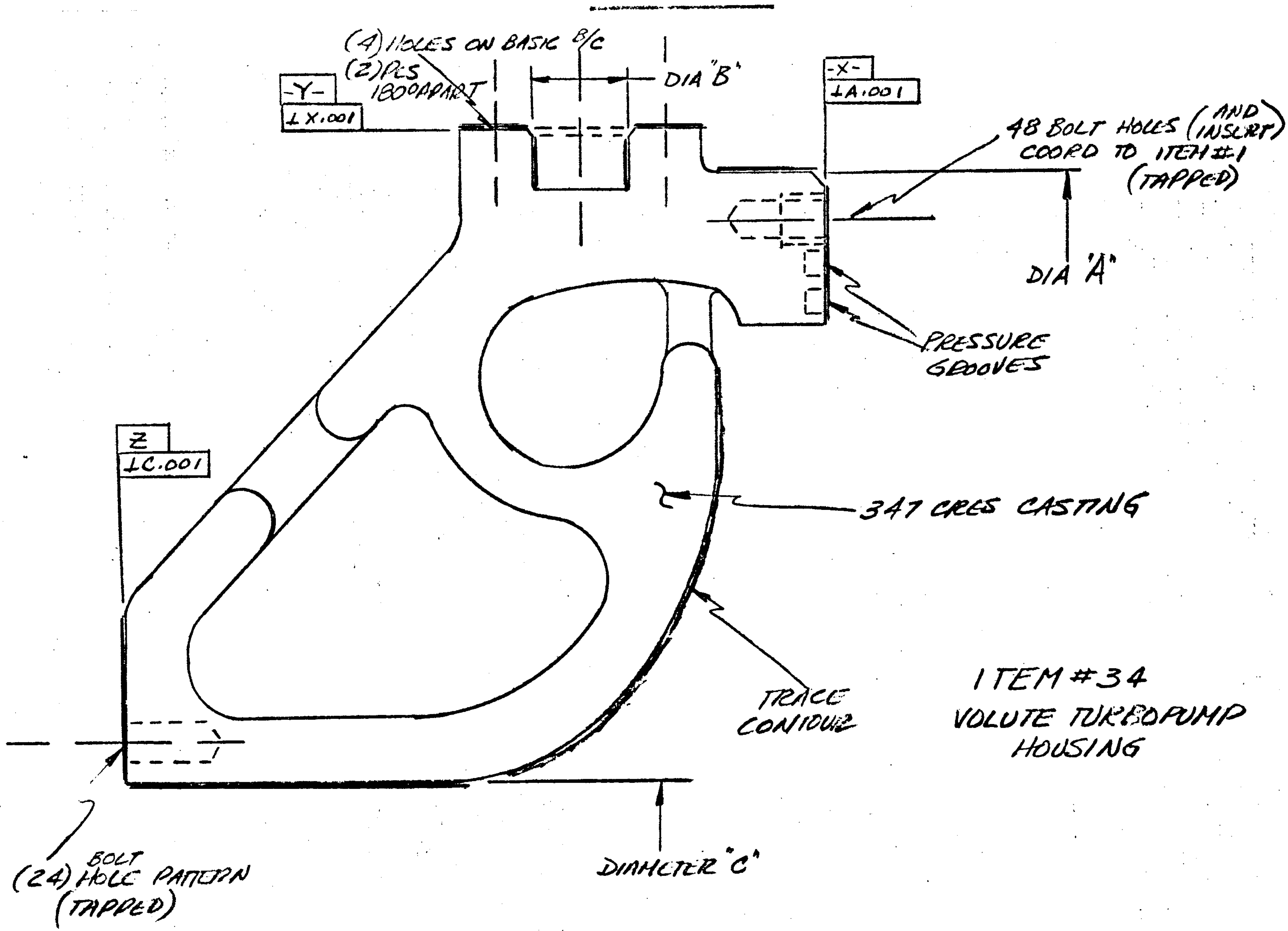
LAMCO INDUSTRIES, INC.

SHEET 2 OF 2

PLANNER CHG	CUSTOMER	PART NAME	PART NO.	CHG LTR	W/O NO.
N/C	AGC	TURBOPUMP HOUSING	ITEM #34	N/C	8132

OPER NO.	MACH	EST TIME	OPERATION DESCRIPTION	F.A.	DIM.	TOL.	L.A.	MOVE LOG INSP LOG	INSP SEQ	DIM CLASS	DWG ZONE	TOOLING	INSP METHOD
50	DRILL		DRILL (48) BOLT HOLES (MATCH TO ITEM #1)									DRJI	
	PRESS		DRILL (24) BOLT HL. PATTERN ON SURFACE "Z"									DRPE	
	10 10	HRS											
	23												
60	SHOP		TAP ALL HOLES PER B/P (REF INSERT)									HOFX	
			& DEBURR HOLES COMP .005 MAX										
	35 35	HRS	INSTALL INSERTS										
	33												
70	INSP		INSPECT THROUGH OPER 60										
80	PROCESS		PROCESS PER B/P										
90	P/C		STORE FOR N/ASSY OR										
			PREPARE FOR SHIPPING TO CUSTOMER										

FORM NO. F-3



ITEM #34
VOLUTE TURBOPUMP
HOUSING

APPENDIX F

SAMPLE ESTIMATE FOR BASE CASE FUEL TURBOPUMP
SUBCOMPONENTS FROM
PARAGON TOOL, DIE, AND ENGINEERING COMPANY

ITEM # 1

TOOLING & MISC. QUOTATION SHEET — DATE: 10/23/69

COMPANY: A.G.C. SAC — SCRAP ALLOW:

PART NAME: HOUSING BEARING BACK PLATE — P/N: — NO. PARTS: 1

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
347 CASTING				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN CASTING COMPLETE	75.0	11.95	896.25	
3. MILLING OPERATIONS (ITEMIZE)				
DRILL & TAP ALL HOLES - PORTS & SPECIAL MILLING	235.0	11.95	2808.25	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	40.0	9.15	366.00	
7. INSPECTION	35.0	11.30	395.50	
TOTAL SHOP OPERATIONS			4466.00	4466.00
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
LATHE FIXTURE			750.00	
MILL FIXTURE			750.00	
MISC. TOOLS & PORTS			1000.00	
TOTAL TOOLING			2500.00	
11. ENGINEERING				

QUOTED PRICE: — TOTAL TOOLING & ENGR:

QUOTED TOOLING: 2500.00

DELIVERY:

REMARKS

1 PC - 4466.00
10 PC - 3,520.00
40 PC - 3150.00

TOOLING & MISC. QUOTATION SHEET ITEM # 2

DATE: OCT/23/69

COMPANY A.G.C. SAC

SCRAP ALLOW:

PART NAME: SHAFT P/N:

NO. PARTS 1

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO-X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	25.0	11.95	29875	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
DRILL HOLES	8.0	11.95	95.60	
5. ASSEMBLY				
6. BENCH	2.0	9.15	18.30	
7. INSPECTION	5.0	11.30	56.50	
TOTAL SHOP OPERATIONS			469.15	469.15
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE) NONE				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: -0-

DELIVERY:

REMARKS

1 PC-469.15

10 PC-368.00

40 PC-332.00

320

TOOLING & MISC. QUOTATION SHEET ITEM # 3.5 DATE: OCT-23-69

COMPANY A.G.C. SAC SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

SPACER BEARING - UPPER

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO - X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	4.0	11.95	47.80	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH				
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			59.10	59.10
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE) - NONE				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: -0-

DELIVERY:

REMARKS

321

1PC-59.10
10PC. 46.50
40PC. 42.00

ITEM # 5

TOOLING & MISC. QUOTATION SHEET

DATE: OCT-23-69

COMPANY A.G.C. SAC.

SCRAP ALLOW:

PART NAME: SPACER BRG. P/N:

NO. PARTS 1

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO- X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	15.0	11.95	191.20	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	10.0	11.95	119.50	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	2.0	9.15	18.30	
7. INSPECTION	2.0	11.30	22.60	
TOTAL SHOP OPERATIONS			351.60	351.60
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				
QUOTED PRICE:	TOTAL TOOLING & ENGR:			

QUOTED TOOLING: — 0 —

DELIVERY:

322

REMARKS

1 Pc - 351.60
10 Pc - 278.00
40 Pc - 249.00

TOOLING & MISC. QUOTATION SHEET ITEM # 6.5 DATE: 10-23-69

COMPANY ACC SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

SPACER, BEARING LOWER

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO - X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	4.0	11.95	47.80	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH				
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			59.10	59.10
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: - 0 -

DELIVERY:

REMARKS

323

1 Pc - 59.10

10 Pc - 46.50

40 Pc - 41.40

TOOLING & MISC. QUOTATION SHEET ITEM # 8 DATE: 10-23-69

COMPANY A.G.C. S.A.C. SCRAP ALLOW:

PART NAME: COUPLING TURBINE P/N: NO. PARTS 1

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO-X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	40.0	1195	478.00	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	25.0	11.95	298.75	
4. MISC. OPERATIONS (ITEMIZE)				
DRILL 6 HOLES - ETC	10.0	1195	119.50	
GRINDING I.D. & O.D.	8.0	1195	95.60	
5. ASSEMBLY				
6. BENCH	5.0	9.15	45.75	
7. INSPECTION	3.0	1130	33.90	
TOTAL SHOP OPERATIONS			1071.50	1071.50
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

1PC - 1071.50
10PC - 848.00
40PC - 760.00

REMARKS

324

TOOLING & MISC. QUOTATION SHEET   ITEM #9   DATE: 10-23-6?

COMPANY A.G.C. [illegible]   SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

BOLT, SHAFT COUPLING

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	200	1195	239.00	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	80	11.95	95.60	
4. MISC. OPERATIONS (ITEMIZE)				
GRIND	50	1195	59.75	
5. ASSEMBLY				
6. BENCH	1.0	9.15	9.15	
7. INSPECTION	20	11.30	22.60	
TOTAL SHOP OPERATIONS			426.10	426.10
8. OUTSIDE PRODUCTION (ITEMIZE)				
SPLINE			35.00	
TOTAL OUTSIDE PRODUCTION				35.00
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

REMARKS

1 Pc – 461.10
10 Pc – 361.00
40 Pc – 322.00

TOOLING & MISC. QUOTATION SHEET ITEM #10 DATE: 10-23-69

COMPANY A.G.C. SAC. SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

NUT COUPLING

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
A-286				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	4.0	11.95	47.80	
3. MILLING OPERATIONS (ITEMIZE)				
MILL SLOTS	2.0	11.95	23.90	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	.5	9.15	4.57	
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			87.57	87.57
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: | TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

326

REMARKS

1 PC - 87.57

10 PC - 68.00

40 PC - 61.00

TOOLING & MISC. QUOTATION SHEET ITEM # 11 DATE: 10-23-67

COMPANY A.G.C. SAC. SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

LABYRINTH, SHAFT

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
PHOS. BRONZE				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	5.0	11.95	59.75	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
DRILL 6 HOLES	3.0	11.95	35.85	
GRIND	2.0	11.95	23.90	
5. ASSEMBLY				
6. BENCH	.5	9.15	4.57	
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			135.37	135.37
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

1 PC — 135.37
10 PC — 106.00
40 PC — 95.50

REMARKS

TOOLING & MISC. QUOTATION SHEET ITEM # 12 DATE: 10-23-69

COMPANY A.G.C. SAC SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

CARRIER, BEARING UPPER

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO-X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	5.0	11.95	59.75	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
GRIND	3.0	11.95	35.85	
5. ASSEMBLY				
6. BENCH	.5	9.15	4.57	
7. INSPECTION	2.0	11.30	22.60	
TOTAL SHOP OPERATIONS			122.77	122.77
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

REMARKS

DELIVERY:

1 PC — 122.77
10 PC — 96.00
40 PC — 87.00

328

TOOLING & MISC. QUOTATION SHEET ITEM #13 DATE: 10-23-68

COMPANY AGC. SAC SCRAP ALLOW:

PART NAME: P/N: NO. PARTS

CARRIER, BEARING LOWER

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO - X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	5.0	1195	59.75	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
GRIND	2.0	1195	23.90	
5. ASSEMBLY				
6. BENCH	5	915	4.57	
7. INSPECTION	2.0	1130	22.60	
TOTAL SHOP OPERATIONS			110.82	110.82
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

REMARKS

1 PC — 110.82

10 PC — 86.50

40 PC — 77.20

329

TOOLING & MISC. QUOTATION SHEET ITEM # 14 DATE: 10-23-69

COMPANY RGC - SAC SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

SPACER SHIM BEARING RETAINING

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO-X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	2.0	11.95	23.90	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
DRILL HOLES	2.0	11.95	23.90	
5. ASSEMBLY				
6. BENCH				
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			59.10	59.10
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				
QUOTED PRICE:	TOTAL TOOLING & ENGR:			

QUOTED TOOLING: -0-

DELIVERY:
330

1 PC - 59.10
10 PC - 46.40
40 PC - 41.40

REMARKS

ITEM # 15

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY A.G.C. SAC.

SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

SPACER, BEARING RETAINING

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO - X				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	3.0	11.95	35.85	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
DRILL HOLES	2.0	11.95	23.90	
5. ASSEMBLY				
6. BENCH				
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			71.00	71.00
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

REMARKS

1 PC — 71.00

10 PC — 55.70

10 PC — 50.30

331

ITEM # 16

TOOLING & MISC. QUOTATION SHEET

DATE: 10-25-69

COMPANY A.G.C. SAC.

SCRAP ALLOW:

PART NAME: LABYRINTH, COUPLING

P/N:

NO. PARTS 1

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
PHOS. BRONZE				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	6.0	11.95	71.70	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
DRILL 12 HOLES	5.0	11.95	59.75	
BRINC	2.0	11.95	23.90	
5. ASSEMBLY				
6. BENCH	.5	9.15	4.57	
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			171.22	171.22
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: -0-

DELIVERY: 332

REMARKS

1 PC - 171.22
10 PC - 134.50
40 PC - 121.70

ITEM # 17

TOOLING & MISC. QUOTATION SHEET

DATE: 10-25-69

COMPANY A.G.C. SAC.

SCRAP ALLOW:

PART NAME: SEAL ASSY, TURBINE COUPLING

P/N:

NO. PARTS 1

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
A-286				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	12.0	11.95	143.40	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	5.0	11.95	59.75	
4. MISC. OPERATIONS (ITEMIZE)				
DRILL 12 HOLES	5.0	11.95	59.75	
GRIND	3.0	11.95	35.85	
5. ASSEMBLY				
6. BENCH	1.0	9.15	9.15	
7. INSPECTION	3.0	11.30	33.90	
TOTAL SHOP OPERATIONS			341.80	341.80
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: -0-

DELIVERY:

REMARKS

333

1 PC — 341.80

10 PC — 268.00

40 PC — 241.00

ROTOR NO. 1

TURBINE/~~STATOR~~ QUOTATION SHEET   ITEM # 18   DATE: 10-23-69

COMPANY A.G.C. SAC.   P/N ________   No. PARTS 1

No. BLADES ?   2D X   3D   DEPTH   MIN. PASS

CUTTER SIZE   MACHINED BLADES   FIR TREE

REMARKS

	HOURS	RATE	COST	TOTAL
1. MATERIAL (Itemize)				
INCO-718				
TOTAL MATERIAL				
2. LATHE OPERATIONS (Itemize)				
TURN COMP. ROUGH & FINISH	60.0	11.95	717.00	
3. PANTOGRAPH	125.0	9.15	1143.75	
4 CUTTERS	10.0	9.15	91.50	
5. MILLING OTHER THAN PANTOGRAPH (Itemize)				
MILL TONGUES & SLOTS	25.0	11.95	298.75	
6. MISCELLANEOUS OPERATIONS (Itemize)				
DRILL HOLES	12.0	11.95	143.40	
7 BENCH	60.0	9.15	549.00	
8. INSPECTION	15.0	11.30	169.50	
TOTAL SHOP OPERATIONS			3112.90	3112.90
9. OUTSIDE PRODUCTION (Itemize)				
TOTAL OUTSIDE PROD.				
10. PACKAGING				
11. TOOLING (Itemize)				
2D MASTER			550.00	
HOLDING FIXTURE			500.00	
TOTAL TOOLING			1050.00	
12. ENGINEERING				

QUOTED PRICE

QUOTED TOOLING 1050.00

DELIVERY:

334

1 PC — 3112.90

40 PC - 2220.00   10 PC — 2460.00

[illegible]

TURBINE/~~STATOR~~ ROTOR QUOTATION SHEET   ITEM #19   DATE: 10-23-69

COMPANY A.G.C.   P/N   No. PARTS /

No. BLADES   2D   3D   DEPTH   MIN. PASS

CUTTER SIZE   MACHINED BLADES   FIR TREE

REMARKS

	HOURS	RATE	COST	TOTAL
1. MATERIAL (Itemize)				
INCO-718				
TOTAL MATERIAL				
2. LATHE OPERATIONS (Itemize)				
TURN COMP. ROUGH & FINISH	600	11.95	717.00	
3. PANTOGRAPH	135.0	9.15	1235.25	
4 CUTTERS	10.0	9.15	91.50	
5. MILLING OTHER THAN PANTOGRAPH (Itemize)				
MILL TONGUES & SLOTS	25.0	11.95	298.75	
6. MISCELLANEOUS OPERATIONS (Itemize)				
DRILL HOLES	12.0	11.95	143.40	
7. BENCH	65.0	9.15	595.69	
8. INSPECTION	15.0	11.30	169.50	
TOTAL SHOP OPERATIONS			3251.09	3251.09
9. OUTSIDE PRODUCTION (Itemize)				
TOTAL OUTSIDE PROD.				
10. PACKAGING				
11. TOOLING (Itemize)				
2D MASTER			550.00	
HOLDING FIXTURE			500.00	
TOTAL TOOLING			1050.00	
12. ENGINEERING				

QUOTED PRICE

QUOTED TOOLING 1050.00

DELIVERY:

3251.09

1 PC — 2560.00

10 PC — 2315 min

40 PC

ITEM # 20

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY AGC INC

SCRAP ALLOW:

PART NAME: BOLT, TURBINE ROTOR

P/N:

NO. PARTS 6

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO - 718				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE (6 PCS)	15.0	11.95	179.25	
3. MILLING OPERATIONS (ITEMIZE)				
MILL	4.0	11.95	47.80	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH				
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			238.35	238.35
8. OUTSIDE PRODUCTION (ITEMIZE)				
THREAD GRIND 2.00 ea. 6			12.00	
TOTAL OUTSIDE PRODUCTION				12.00
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: -0-

DELIVERY:

1 Pc - 250.35
10 Pc - 198.00
40 Pc - 177.00

REMARKS

336

~~TURBINE~~/STATOR QUOTATION SHEET — VANE STATOR — ITEM # 21 — DATE: 10-23-64

COMPANY A.G.C. SAC. P/N ______ No. PARTS ______

No. BLADES ______ 2D X 3D ______ DEPTH ______ MIN. PASS ______

CUTTER SIZE ______ MACHINED BLADES ______ FIR TREE ______

REMARKS

	HOURS	RATE	COST	TOTAL
1. MATERIAL (Itemize)				
INCO - 718				
TOTAL MATERIAL				
2. LATHE OPERATIONS (Itemize)				
TURN SHROUD	20.0	11.95	239.00	
TURN STATOR	10.0	11.95	119.50	
TURN COMPLETE AFTER BRAZE	25.0	11.95	298.75	
3. PANTOGRAPH	90.0	9.15	823.50	
4 CUTTERS	8.0	9.15	73.20	
5. MILLING OTHER THAN PANTOGRAPH (Itemize)				
MISC. MILLING	12.0	11.95	143.40	
6. MISCELLANEOUS OPERATIONS (Itemize)				
DRILL ALL HOLES	25.0	11.95	298.75	
DEBURR AND FIN. ASSY	4.0	9.15	36.60	
7 BENCH	50.0	9.15	457.50	
8. INSPECTION	12.0	11.30	135.60	
TOTAL SHOP OPERATIONS			2625.80	2625.80
9. OUTSIDE PRODUCTION (Itemize)				
BRAZING	65.00			
HT. TREAT	60.00			
TOTAL OUTSIDE PROD.			125.00	125.00
10. PACKAGING				
11. TOOLING (Itemize)				
2D MASTER			550.00	
HOLDING & INDEX FIXTURE			500.00	
TOTAL TOOLING			1050.00	
12. ENGINEERING				

QUOTED PRICE

QUOTED TOOLING 1050.00

DELIVERY:

1 Pc — 2750.80
10 Pc — 2170.00
40 Pc — 1942.00

ITEM # 22

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY A.G.C. IAC

SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

RING ORFICE, LOW PRESSURE

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO · 718				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	8.0	11.95	95.60	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	15.0	11.95	179.25	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	2.0	9.15	18.30	
7. INSPECTION	3.0	11.30	33.90	
TOTAL SHOP OPERATIONS			327.05	327.05
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: - 0 -

1 PC — 327.05
10 PC — 256.00
40 PC — 232.00

DELIVERY:

REMARKS

338

ITEM #23

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY A.G.C. SAC

SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

NUT, RING ORFICE LOW PRESSURE

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
A-286				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	10.0	11.95	119.50	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	15.0	11.95	179.25	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	2.0	9.15	18.30	
7. INSPECTION	3.0	11.30	33.90	
TOTAL SHOP OPERATIONS			350.95	350.95
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE: TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

REMARKS

1 Pc — 350.95
10 Pc — 285.00
40 Pc — 249.00

ITEM # 27

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY A.C.C. SAC.

SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

RING ORFICE - HIGH PRESSURE

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO-718				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	8.0	11.95	95.60	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	15.0	11.95	179.25	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	2.0	9.15	18.30	
7. INSPECTION	3.0	11.30	33.90	
TOTAL SHOP OPERATIONS			327.05	327.05
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: -0-

DELIVERY:

340

1 Pc — 327.05
10 Pc — 256.00
40 Pc — 232.00

REMARKS

ITEM 4 28

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY AGC. SAC.

SCRAP ALLOW:

PART NAME: P/N: NO. PARTS

NUT, RING ORFICE. HIGH PRESURE

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO - 718				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	10.0	11.95	119.50	
3. MILLING OPERATIONS (ITEMIZE)				
MISC MILLING	15.0	11.95	179.25	
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	2.0	9.15	18.30	
7. INSPECTION	3.0	11.30	33.90	
TOTAL SHOP OPERATIONS			350.95	350.95
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: -0-

REMARKS

DELIVERY:

341

1 PC — 350.95
10 PC — 285.00
40 PC — 249.00

VANE DIFFUSER PUMP ITEM # 29 DATE: 10-23-69

~~TURBINE/STATOR~~ QUOTATION SHEET

COMPANY A.G.C. SAC P/N No. PARTS

No. BLADES 2D X 3D DEPTH MIN. PASS 1

CUTTER SIZE MACHINED BLADES FIR TREE

REMARKS	HOURS	RATE	COST	TOTAL
1. MATERIAL (Itemize)				
.347				
TOTAL MATERIAL				
2. LATHE OPERATIONS (Itemize)				
TURN FOR PANTOGRAPH	15.0	11.95	179.25	
FINISH TURN	25.0	11.95	298.75	
3. PANTOGRAPH VANES	60.0	9.15	549.00	
4 CUTTERS	5.0	9.15	45.75	
5. MILLING OTHER THAN PANTOGRAPH (Itemize)				
MISC. MILLING	8.0	11.95	95.60	
6. MISCELLANEOUS OPERATIONS (Itemize)				
GRIND	6.0	11.95	71.70	
DRILL HOLES	10.0	11.95	119.50	
7 BENCH	35.0	9.15	320.25	
8. INSPECTION	10.0	11.30	113.00	
TOTAL SHOP OPERATIONS			1792.80	1792.80
9. OUTSIDE PRODUCTION (Itemize)				
TOTAL OUTSIDE PROD.				
10. PACKAGING				
11. TOOLING (Itemize)				
2D MASTER			550.00	
HOLDING & INDEX			500.00	
TOTAL TOOLING			1050.00	
12. ENGINEERING				

QUOTED PRICE

QUOTED TOOLING 1050.00

DELIVERY:

342

1 PC — 1792.80

40 PC — 1270.00 10 PC — 1420.00

IMPELLER, PUMP ITEM # 30

IMPELLER QUOTATION SHEET DATE 10-23-69

COMPANY A.G.C. P/N NO. PARTS 1

NO. VANES: FULL 6 LONG PARTIAL ___ SHORT PART'L 6 MIN. PASS ___

Cutter Dia. ___ Generate ___ Duplicate ___

	HOURS	RATE	COST	TOTAL
1 MATERIAL (Itemize)				
TITANIUM 5/2				
TOTAL MATERIAL				
2. LATHE OPERATIONS (Itemize)				
TURN TOP GENERATOR	35.0	11.95	418.25	
TURN FOR BACK RIBS	15.0	11.95	179.25	
FINISH TURN & CONTOUR	25.0	11.95	298.75	
3. VANE GENERATION/DUPLICATION	300.0	9.95	2985.00	
4. CUTTERS	25.0	9.95	248.75	
5. MILLING OTHER THAN VANE GEN. (Itemize)				
MILL BACK VANES	50.0	11.95	597.50	
MILL CLUTCH LUGS	15.0	11.95	179.25	
SETUP & CUT SAMPLE TRACK	150.0	9.50	1425.00	
6. MISC. OPERATIONS (Itemize)				
DRILL HOLES & TAP	15.0	11.95	179.25	
TRIM VANES	20.0	11.95	239.00	
7. BENCH	200.0	9.15	1830.00	
8. INSPECTION	50.0	11.30	565.00	
TOTAL SHOP OPERATION			9145.00	9145.00
9. OUTSIDE PRODUCTION (Itemize)				
TOTAL OUTSIDE PROD.				
10. PACKAGING				
11. TOOLING (Itemize)				
2 BARREL CAMS			3000.00	
2 SWING HEAD CAMS			2400.00	
1 KNEE CAM			600.00	
1-INDEX PLATE			1500.00	
ARBORS & TEMP. & MISC.			2000.00	
TOTAL TOOLING			9500.00	
12. ENGINEERING				

QUOTED PRICE	DELIVERY:	1 PC —	9145.00
QUOTED TOOLING 9500.00		10 PC —	7220.00
Rev. 3 Regan 5-24-60		40 PC —	6490.00

INDUCER ITEM # 31

~~IMPELLER~~ QUOTATION SHEET

DATE OCT-23-69

COMPANY AGC. SAC P/N

NO. PARTS 1

NO. VANES: FULL 4 LONG PARTIAL ___ SHORT PART'L ___ MIN. PASS ___

Cutter Dia. ___ Generate ___ Duplicate ___

	HOURS	RATE	COST	TOTAL
1 MATERIAL (Itemize)				
TITANIUM 5/2				
TOTAL MATERIAL				
2. LATHE OPERATIONS (Itemize)				
TURN FOR GEN.	60.0	11.95	717.00	
TURN FOR SPLINE	20.0	11.95	239.00	
FINISH TURN & CONTOUR	25.0	11.95	298.75	
ROUGH GEN.	100.0	9.95	995.00	71 133
3. VANE GENERATION/DUPLICATION	125.0	9.95	1243.75	89 167
4. CUTTERS	5.0	9.95	149.25	11 20
5. MILLING OTHER THAN VANE GEN. (Itemize)				
KEYS & TOOLING HOLE	5.0	11.95	59.75	
TRIM PARTIALS	20.0	11.95	239.00	14 27
6. MISC. OPERATIONS (Itemize)				
SETUP & OUT SAMPLE TRIM	100.0	9.50	950.00	
7. BENCH	80.0	9.15	732.00	57 107
8. INSPECTION	25.0	11.30	282.50	
TOTAL SHOP OPERATION			5906.00	5906.00
9. OUTSIDE PRODUCTION (Itemize)				
THREAD GRIND			125.00	
SPLINE			100.00	
TOTAL OUTSIDE PROD.			225.00	225.00
10. PACKAGING				
11. TOOLING (Itemize)				
BARREL CAM			1200.00	
KNEE CAM			450.00	
INDEX PLATE			1000.00	
SPUDS - TEMP - ETC.			1550.00	
TOTAL TOOLING			4200.00	
12. ENGINEERING				

QUOTED PRICE

QUOTED TOOLING 4200.00

DELIVERY:

1 PC — 6131.00

10 PC — 4840.00

40 PC — 4300.00

344 Rev. 3 Rogan 5-24-60

ITEM # 32

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY A.G.C. SAC.

SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

NUT ASS'Y IMPELLER RETAINING

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
ALUMINUM				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE & THREAD	30.0	11.95	358.50	
3. MILLING OPERATIONS (ITEMIZE)				
4. MISC. OPERATIONS (ITEMIZE)				
5. ASSEMBLY				
6. BENCH	.5	9.15	4.57	
7. INSPECTION	1.0	11.30	11.30	
TOTAL SHOP OPERATIONS			374.37	374.37
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
TOTAL TOOLING				
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: — 0 —

DELIVERY:

REMARKS

1 Pc — 374.37
10 Pc — 292.00
40 Pc — 260.00

345

ITEM # 33

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY A.G.C SAC

SCRAP ALLOW:

PART NAME: MANIFOLD ASSY. TURBINE INLET

P/N:

NO. PARTS 1

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
INCO-718 CASTING				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	125.0	11.95	1493.75	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	75.0	11.95	896.25	
4. MISC. OPERATIONS (ITEMIZE)				
DRILL ALL HOLES & PORTS	225.0	11.95	2688.75	
5. ASSEMBLY				
6. BENCH	40.0	9.15	366.00	
7. INSPECTION	30.0	11.30	339.00	
TOTAL SHOP OPERATIONS			5783.75	5783.75
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
MILL HOLDING FIXTURE			750.00	
LATHE HOLDING FIXTURE			750.00	
TOTAL TOOLING			1500.00	
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: 1500.00

DELIVERY:

REMARKS

346

1 PC — 5783.75
10 PC — 4540.00
40 PC — 4050.00

ITEM #34

TOOLING & MISC. QUOTATION SHEET

DATE: 10-23-69

COMPANY A.G.C. SAC.

SCRAP ALLOW:

PART NAME: P/N: NO. PARTS 1

VOLUTE PUMP

	HOURS	RATE	COST	TOTAL
1. MATERIAL (ITEMIZE)				
347- CASTING				
TOTAL MATERIAL				
2. LATHE OPERATIONS (ITEMIZE)				
TURN COMPLETE	75.0	11.95	896.25	
3. MILLING OPERATIONS (ITEMIZE)				
MISC. MILLING	50.0	11.95	597.50	
4. MISC. OPERATIONS (ITEMIZE)				
DRILL ALL HOLES & PORTS	150.0	11.95	1792.50	
5. ASSEMBLY				
6. BENCH	25.0	9.15	228.75	
7. INSPECTION	20.0	11.30	226.00	
TOTAL SHOP OPERATIONS			3741.00	3741.00
8. OUTSIDE PRODUCTION (ITEMIZE)				
TOTAL OUTSIDE PRODUCTION				
9. PACKAGING				
10. TOOLING (ITEMIZE)				
MILL HOLDING FIXTURE			750.00	
LATHE HOLDING FIXTURE			750.00	
TOTAL TOOLING			1500.00	
11. ENGINEERING				

QUOTED PRICE:

TOTAL TOOLING & ENGR:

QUOTED TOOLING: 1500.00

DELIVERY:

REMARKS

347

1 PC — 3741.00

10 PC — 2900.00

40 PC — 2610.00

APPENDIX G

SAMPLE ESTIMATE FOR BASE CASE FUEL TURBOPUMP SUBCOMPONENTS FROM BOBBITT & PRUETT MANUFACTURING COMPANY

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635–1830

COST ASSEMBLY SHEET

PART or JOB NO. Item #2 DATE 12/30/69 DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			Dynamic balancing.
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW		3.00	PER cut
SAND			
GRINDING	8 hrs.	80.00	"C" Dia. VERY Difficult
DRILL			REQUIRES INTERNAL Grinding.
MILL	3 hrs.	30.00	Hole Pattern
TAP or THREAD			
LATHE	16 hrs.	160.00	.001 AXIAL Dim. difficult.
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING		$90.00	thd. Gage
MISC.		$45.00	1 Pt.
TOTALS		$318.00	

351

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635–1830

COST ASSEMBLY SHEET

PART or JOB NO. Item 5 DATE ______ DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW	10 Min	2.00	
SAND			
GRINDING	2 hr.	20.00	
DRILL			
MILL	2 1/3	23.00	
TAP or THREAD			
LATHE	3 1/2	35.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING			
MISC.			
TOTALS			

352

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635–1830

COST ASSEMBLY SHEET

PART or JOB NO. Item 3.5 + 6.5 DATE ______ DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING			
DRILL			
MILL			
TAP or THREAD			
LATHE	1 hr. 15 Min	12.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING			
MISC.			
TOTALS			

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635-1830

COST ASSEMBLY SHEET

PART or JOB NO. ITEM # 9 DATE ____________ DELIVERY ____________ QTY. ____________

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING			
DRILL			
MILL			
TAP or THREAD			
LATHE	4 hr.	40.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING			
MISC.	1 1/2	15.00	SPLINE
TOTALS			

354

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635-1830

COST ASSEMBLY SHEET

PART or JOB NO. Item #11 DATE ______ DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING			
DRILL			
MILL	1 hr.	10.00	
TAP or THREAD			
LATHE	4 hr.	40.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING			
MISC.			
TOTALS			

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635–1830

COST ASSEMBLY SHEET

PART or JOB NO. Item #12 DATE ______ DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING			
DRILL			
MILL	1/2 hr.	5.00	
TAP or THREAD			
LATHE	4.5 hr.	45.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING			
MISC.			

356 TOTALS

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635–1830

COST ASSEMBLY SHEET

PART or JOB NO. ITEM #15 DATE ______ DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING			
DRILL			
MILL	1½	15.00	
TAP or THREAD			
LATHE	7½	75.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING			
MISC.			
TOTALS			

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635–1830

COST ASSEMBLY SHEET

PART or JOB NO. ITEM #20 DATE ______ DELIVERY ______ QTY. 60 EA.

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING	9 hr.	90.00	
DRILL			
MILL	4 hr.	40.00	
TAP or THREAD			
LATHE	50 hr.	500.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING			
MISC.			

358 TOTALS

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635-1830

COST ASSEMBLY SHEET

PART or JOB NO. Item #28 DATE ______ DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING			
DRILL			
MILL			
TAP or THREAD			
LATHE	9 hr.	90.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING	14 hr.	$140.00	Lathe Fixt.
MISC.			
TOTALS			

BOBBITT & PRUETT MFG. CO.

11351 PYRITE WAY RANCHO CORDOVA, CALIF. 635-1830

COST ASSEMBLY SHEET

PART or JOB NO. ITEM #32 DATE ______ DELIVERY ______ QTY. ______

PROCESS	TIME	COST	TROUBLE AREA & REMARKS
MATERIAL			
HEAT TREAT			
PLATING			
PAINTING			
PACKAGING			
INSPECTION			
SHIPPING			
CERTIFICATIONS			
SPECIFICATIONS			
SAW			
SAND			
GRINDING			
DRILL			
MILL			
TAP or THREAD			
LATHE	10 HR.	100.00	
WELDING			
FORMING, HAND			
FORMING, PUNCH PRESS			
DEBURRING			
SAND BLAST			
PLANNING			
ASSEMBLY			
DESIGN			
TOOLING	7 hr.	70.00	Lathe tracer temp.
MISC.			

360 TOTALS

APPENDIX H

BASE CASE FUEL TURBOPUMP COST ANALYSIS

OPERATION

ITEM NO. 1

PN 113697/2

FUEL

LOW COST TURBOPUMP STUDY

UNIT COST (BASE CASE)

COST ANALYSIS LAMCO (MACH) PERFECTO CAST (CASTING)

NAME HOUSING, BEARING / BACK PLATE		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY																
	SAL																
2. PROCUREMENT PLANNING PERFECTO	~~HRLY~~	20.0	3.0	1.5	6.96	135.20	20.88	10.44	351.52	54.29	27.14	69.36	10.71	5.36	556.08	85.88	42.94
LAMCO	SAL	30.0	3.0	1.5		208.80	20.88	10.44	542.80	54.29	27.14	107.10	10.71	5.36	858.70	85.88	42.94
3. TOOLING PERFECTO CAST	~~HRLY~~	—	—	—	—	2100.00	—	—	—	—	—	299.25	—	—	2399.25	—	—
LAMCO	~~SAL~~			—	—	1800.00	—	—	—	—	—	256.50	—	—	2056.50	—	—
4. RAWSTOCK	HRLY																
	SAL																
5. CASTINGS ~~[illegible]~~ PERFECTO CAST	~~HRLY SAL~~	143.0	100.0	89.0	14.00	2000.00	1400.00	1250.00	—	—	—	285.00	199.50	178.13	2285.00	1599.50	1428.13
6. MACHINING (LAMCO)	HRLY SAL	300	250	230	12.00	3600.00	3000.00	2760.00	—	—	—	573.00	427.50	393.30	4173.00	3427.50	3153.30
7. WELDING	HRLY																
	SAL																
8. ASSY & FAB QE	HRLY																
	SAL																
9. CLEANING	HRLY																
	SAL																
10. Q C PLANNING	HRLY																
	SAL																
11. INSPECTION, SOURCE PERFECTO	~~HRLY~~	15.0	7.5	5.00	6.96	104.00	52.20	34.80	270.40	135.72	90.48	53.35	26.78	17.85	427.75	214.70	143.13
LAMCO	SAL	30.0	10.0	7.0		208.80	69.60	48.72	542.88	180.96	126.67	107.11	35.70	24.99	858.79	286.26	200.38
12. INSPECTION, REC (PERFECTO)	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	2	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
13. INSIDE LIAISON	HRLY																
	SAL																
14. SHIPPING PERFECTO	~~HRLY~~	—	—	—	—	40.00	28.00	25.00	—	—	—	5.70	3.99	3.56	45.70	31.99	28.56
LAMCO	~~SAL~~	—	—	—	—	72.00	60.00	55.00	—	—	—	10.26	8.55	7.84	82.26	68.55	62.84
15. INSPECTION, REC. (LAMCO)	HRLY	1.0	1.0	1.0	6.96	6.96	6.96	6.96	18.10	18.10	18.10	3.57	3.57	3.57	28.63	28.63	28.63
	SAL	2.0	1.5	1.0		13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.35	42.94	28.63
16.	HRLY																
	SAL																
TOTAL UNIT COST						6906.04	4671.34	4217.73			TOOLING	4455.75			7440.94	[illegible]	5198.14

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *

INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

364

OPERATION
ITEM NO. 2
PN 1136913

10-28-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME SHAFT

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL	—	—	—													
2. PROCUREMENT PLANNING	SAL	9.0	1.0	.7	6.96	62.64	6.96	4.87	162.86	18.10	12.66	32.13	3.57	2.50	257.63	28.63	20.03
3. TOOLING	HRLY SAL	—	—	—	—	1780.00	—	—	—	—	—	253.65	—	—	2033.65	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	328.00	219.00	197.00	—	—	—	46.74	31.21	28.07	374.74	250.21	225.07
5. CASTINGS OR FORGINGS	HRLY SAL	—	—	—													
6. MACHINING	HRLY SAL	75	50	45	12.00	900.00	600.00	540.00	—	—	—	128.35	85.50	76.95	1028.35	685.50	616.95
7. WELDING	HRLY SAL	—	—	—													
8. ASSY & FAB QE	HRLY SAL	—	—	—													
9. CLEANING	HRLY SAL	—	—	—													
10. Q C PLANNING	HRLY SAL	—	—	—													
11. INSPECTION (REC)	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION	HRLY SAL	—	—	—													
13. INSIDE LIAISON	HRLY SAL	—	—	—													
14. SHIPPING	HRLY SAL					18.00	18.00	18.00	—	—	—	2.57	2.57	2.57	20.57	20.57	20.57
15. SUPPLIER QC (5HR/1000 OP) .5 HR MIN.	SAL	4.5	3.0	2.7	6.96	31.32	20.88	18.79	81.43	54.29	48.85	16.07	10.71	9.64	128.82	85.88	77.28
16.	HRLY SAL																
TOTAL UNIT COST						1345.00	868.36	782.69			TOOLING	2033.65			1834.36	1088.22	974.32

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE - NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *
INHOUSE RATE AT $6.96/HR (SAL) *

E W SULLIVAN X 7872

✓ 11-7-69

OPERATION

ITEM NO. 3 ~~441647~~

PN 1136914

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS (ITI) REF: PO L108824 9-26-69 ($463.13 ea QUAN. OF 12)

(2 ea TO MATCHED SET)

NAME BEARING, BALL-SET 60MM

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.14	3.57	429.40	57.25	28.63
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL					COST ea 663.00	 510.00	 408.00									
5. CASTINGS OR FORGINGS	HRLY SAL					QUANTITIES ORDERED 6	 50	 180									
6. MACHINING *QUANTITIES SHOWN INCLUDE SPARES*	~~HRLY~~ ~~SAL~~	—	—	—	—	3978.00	2550.00	1836.00	—	—	—	566.81	363.38	261.63	4544.81	2913.38	2097.63
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE	~~HRLY~~ SAL	2.0	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
12. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 13.92	4.87 10.44	4.87 6.96	12.66 36.19	12.66 27.14	12.66 18.10	2.50 7.14	2.50 5.36	2.50 3.57	20.03 57.25	20.03 42.94	20.03 28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	120.00	80.00	60.00	—	—	—	17.10	11.40	8.55	137.10	91.40	68.55
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						4235.11	2669.67	1921.75							5245.[illegible]	3167.[illegible]	2272.19

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

EW SULLIVAN X7872

OPERATION
ITEM NO. 5
PN 1136915

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

10-29-69

NAME SPACER, BEARING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.00	.6	.5	6.96	20.88	4.18	3.48	54.29	10.87	9.05	10.71	2.14	1.79	85.88	17.19	14.32
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL					54.00	36.00	32.40	—	—	—	7.70	5.13	4.62	61.70	41.13	37.02
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	25.0	18.0	16.0	12.00	300.00	216.00	192.00	—	—	—	42.75	30.78	27.36	342.75	246.78	219.36
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION - REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION - SOURCE	[redacted] SAL	1.50	1.00	.9	6.96	10.44	6.96	6.26	27.14	18.10	16.27	5.36	3.57	3.21	42.94	28.63	25.76
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL					6.00	4.32	3.84	—	—	—	.86	.62	.55	6.86	4.94	4.39
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						397.24	270.94	241.46							564.49	352.97	315.35

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *
INHOUSE RATE AT $6.96/HR (SAL) *

E W SULLIVAN x 7872

OPERATION
ITEM NO. 35 + 65
PN 1156926

10-29-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME SPACER BEARING -UPPER -LOWER
NOTE: TWO EA. REQUIRED

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.00	.6	.5	6.96	20.88	4.18	3.48	54.29	10.87	9.05	10.71	2.14	1.79	85.88	17.19	14.32
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL					18.00	12.00	10.80	—	—	—	2.57	1.71	1.54	20.57	13.71	12.34
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	8.00	6.00	4.00	12.00	96.00	72.00	48.00	—	—	—	13.68	10.26	6.84	109.68	82.26	54.84
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, ~~REC~~ SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.49	10.87	3.57	2.57	2.14	28.63	22.62	17.19
12. INSPECTION, ~~SOURCE~~ REC	HRLY ~~HRLY~~	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	.5	.15	.15	6.96	3.48	1.04	1.04	9.05	2.70	2.70	1.79	.53	.53	14.32	4.27	4.27
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL					2.00	2.00	2.00	—	—	—	.29	.29	.29	2.29	2.29	2.29
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						149.76	99.23	71.94	←THIS COST FOR UNIT QUAN OF TWO→						271.40	152.32	115.22

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

EW SULLIVAN

368

OPERATION
ITEM NO. B
PN 1136916

10-29-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME COUPLING, TURBINE

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	1.0	.7	6.96	31.32	6.96	4.87	81.43	18.10	12.66	16.67	3.57	2.50	129.42	28.63	20.03
3. TOOLING	HRLY SAL	—	—	—		500.00			—	—	—	71.25	—		571.25	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	153.00	102.00	91.80	—	—	—	21.80	14.54	13.08	174.80	116.54	104.88
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	60.00	40.00	35.00	12.00	720.00	480.00	420.00	—	—	—	102.60	68.40	59.85	822.60	548.40	479.85
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.21	10.03 4.21
12. INSPECTION SOURCE	~~HRLY~~ SAL	3.60	2.40	2.10	6.96	25.06	16.70	14.62	65.16	43.42	38.01	12.86	8.57	7.50	103.08	68.69	60.13
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	14.40	9.60	8.40	—	—		2.05	1.37	1.20	16.45	10.97	9.60
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						949.70	618.74	549.17			TOOLING	571.25			1270.70	787.53	688.79

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

/10-27-69

OPERATION

ITEM NO. 9

PN BOLT, 1136917

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME BOLT, SHAFT-COUPLING		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	1.0	.5	6.96	31.32	6.96	3.48	81.43	18.10	8.92	16.07	3.57	1.67	128.82	28.63	14.07
3. TOOLING	HRLY SAL	—	—	—	—	300.00	—	—	—	—	—	42.75	—	—	342.75	—	—
4. RAWSTOCK	HRLY SAL	—	—	—		13.50	9.00	8.10	—	—	—	1.92	1.28	1.15	15.42	10.28	9.25
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	26	15	12	12.00	312.00	180.00	144.00	—	—	—	44.46	25.65	20.52	356.46	205.65	164.52
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	.5	.15	.15	6.96	3.48	1.04	1.04	9.05	2.70	2.70	1.79	.53	.53	14.32	4.27	4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.5	.9	.7	6.96	10.44	6.26	4.87	27.14	16.28	12.66	5.36	3.21	2.50	42.94	25.75	20.03
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	6.00	3.50	3.00	—	—	—	.86	.50	.43	6.86	4.00	3.43
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						377.13	209.20	166.93		TOOLING	342.75				574.25	288.[illegible]	225.[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

EW SULLIVAN X 7872

370

OPERATION
ITEM NO. 10
PN 1136918

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

10-30-69

NAME NUT, COUPLING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	SAL	3.0	.6	.5	6.96	20.88	4.17	3.48	54.29	10.87	9.05	10.71	2.14	1.79	85.88	17.18	14.32
3. TOOLING	HRLY SAL					150.00	.	—	—	—	—	21.38	—	—	171.38	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	4.88	3.25	2.93	—	—	—	.70	.46	.42	5.58	3.71	3.35
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	4.0	2.0	1.0	12.00	48.00	24.00	12.00	—	—	-	6.84	3.42	1.71	54.84	27.42	13.71
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	.5	.15	.15	6.96	3.48	1.04	1.04	9.05	2.70	2.70	1.77	.53	.53	14.30	4.27	4.27
12. INSPECTION, SOURCE	SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.52	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	1.00	.75	.75	—	—	-	.14	.10	.10	1.14	.85	.85
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						87.64	41.23	26.82		TOOLING	171.38				200.42	86.09	63.78

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

OPERATION
ITEM NO. 11
PN 1136919

10-30-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME LABYRINTH, SHAFT

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	.9	.7	6.96	31.32	6.27	4.87	81.43	16.22	12.66	16.07	3.20	2.50	128.82	25.66	20.03
3. TOOLING	HRLY SAL	—	—	—	—	90.00	—	—	—	—	—	12.83	—	—	102.83	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	22.50	15.00	13.50	—	—	—	3.21	2.14	1.92	25.71	17.14	15.42
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	7.0	4.0	3.0	12.00	84.00	48.00	36.00	—	—	—	11.97	6.84	5.13	95.97	54.84	41.13
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.28 1.79	1.25 .52	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.5	.5	6.96	6.96	3.48	3.48	18.10	9.05	9.05	3.57	1.79	1.79	28.63	14.32	14.32
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—			2.00	1.50	1.00	—	—	—	.22	.21	.14	2.23	1.71	1.14
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						152.70	77.70	62.33			TOOLING	102.83			305.[illegible]	127.96	106.[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

371

372.

OPERATION

ITEM NO. 12

PN 1136720

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

10-30-69

NAME CARRIER, BEARING-UPPER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.00	1.00	.5	696	4176	696	348	10858	1810	905	2142	357	179	15934	2863	1433
3. TOOLING	HRLY SAL	—	—	—	—	15000	—	—	—	—	—	2138	—	—	17138	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	5850	3900	3510	—	—	—	834	556	500	6684	4456	4010
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	14.0	10.0	8.0	1200	16800	12000	11200	—	—	—	2394	1710	1596	19194	13710	12796
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	487	244	244	244	634	634	634	125	125	125	1003	1003	1003
	SAL	.5	.15	.15	696	348	104	104	905	270	270	179	53	53	1433	427	427
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	1.0	1.0	696	696	696	696	1810	1810	1810	357	357	357	2863	2863	2863
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	300	240	225	—	—	—	43	34	32	343	274	257
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						28414	17890	16327				TOOLING		17133	47458	15596	22787

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

10-30-69

OPERATION
ITEM NO. 13
PN 1136921

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME CARRIER, BEARING-LOWER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.0	1.0	.5	6 96	41 76	6 96	3 48	108 54	18 10	9 05	21 42	3 57	1 79	159 39	28 63	14 32
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	41 00	27 00	24 30	—	—	—	5 84	3 85	3 46	46 84	30 75	27 76
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	12.0	8.5	7.0	12 00	144 00	102 00	84 00	—	—	—	20 52	14 54	11 98	164 52	116 54	95 98
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4 87	2 44	2 44	2 44	6 34	6 34	6 34	1 25	1 25	1 25	10 03	10 03	10 03
	SAL	.5	.15	.15	6 96	3 48	1 04	1 04	9 05	2 70	2 70	1 79	52	52	14 32	4 22	4 22
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	1.0	1.0	6 96	6 96	6 96	6 96	18 10	18 10	18 10	3 57	3 52	3 52	28 63	29 63	29 63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—		3 00	2 40	2 25	—	—	—	43	34	32	3 43	2 74	2 57
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						292 64	148 70	124 47				TOOLING-NONE			427 16	221 69	183 [illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7972

OPERATION
ITEM NO. 14
PN 1136922

11-4-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS (PARAGON)

NAME SPACER, SHIM-BEARING RETAINING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	.5	.5	696	2088	348	348	5429	905	905	1071	179	179	8588	1432	1432
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	3600	2400	2160	—	—	—	513	342	308	4113	2742	2468
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING LATHE / DRILL / INSPECT	HRLY SAL	2.0 / 2.0 / 1.0	1.6 / 1.6 / .8	1.4 / 1.4 / .7	11.95 / 11.95 / 11.30	5910	4640	4140	—	—	—	842	661	590	6752	5301	4730
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	487	244	244	244	634	634	634	125	125	125	1003	1003	1003
	SAL	.5	.15	.15	696	348	104	104	905	270	270	179	53	53	1432	427	427
12. INSPECTION SOURCE	~~HRLY~~ SAL	1.0	.8	.6	696	696	557	418	1810	1448	1087	357	287	214	2863	2262	1719
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	125	100	100	—	—	—	18	14	14	143	114	114
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						13011	8393	7514							24894	13281	11893

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN x 7872

10-30-69

OPERATION
ITEM NO. 15
PN 1136923

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME SPACER, BEARING-RETAINING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.0	1.0	.5	6.96	41.76	6.96	3.48	108.58	18.10	9.05	21.42	3.52	1.79	159.39	22.09	14.33
3. TOOLING	HRLY SAL	—	—	—	—	110.00	—	—	—	—	—	15.68	—	—	125.68	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	18.00	12.00	10.80	—	—	—	2.57	1.71	1.54	20.57	13.71	12.34
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	6.0	4.0	3.0	12.00	72.00	48.00	36.00	—	—	—	10.26	6.84	5.13	82.26	54.84	41.13
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	.5	.15	.15	6.96	3.48	1.04	1.04	9.05	2.70	2.70	1.79	.53	.53	14.32	4.27	4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	1.0	1.0	6.96	6.96	6.96	6.96	18.10	18.10	18.10	3.57	3.57	3.57	28.63	28.63	28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	2.00	1.50	1.50	—	—	—	.29	.21	.21	2.29	1.71	1.71
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						146.64	78.90	62.22					TOOLING	125.68	317.49	141.82	111.42

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

EW SULLIVAN x7872

375

376

/10-30-69

OPERATION

ITEM NO. 16

PN LABYRINTH, COUPLING

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME PN 1136924

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.0	1.0	.5	696	4176	696	348	10858	1810	905	2142	357	179	15739	2863	1432
3. TOOLING	HRLY SAL	—	—	—	—	11000	—	—	—	—	—	1568	—	—	12568	—	—
4. RAWSTOCK	HRLY SAL					2700	1800	1620	—	—	—	335	257	231	3035	2057	2051
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	8.0	5.0	4.0	1200	9600	6000	4800	—	—	—	1368	855	684	10968	6855	5484
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	487	244	244	244	634	634	634	125	125	125	1003	1003	1003
	SAL	.5	.15	.15	696	348	104	104	905	270	270	179	53	53	1432	427	427
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	1.0	1.0	696	696	696	696	1810	1810	1810	357	357	357	2863	2863	2863
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL					200	150	150	—	—	—	29	21	21	229	171	171
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						17964	9690	7962					TOOLING	12563	35519	16239	13931

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

110-31-69

OPERATION
ITEM NO. 17
PN 1136925

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME SEAL ASSY, TURBINE COUPLING		MAN HOURS 1	MAN HOURS 10	MAN HOURS 40	RATE PER HR	NET DOLLARS 1	NET DOLLARS 10	NET DOLLARS 40	DLO AT 260%* 1	DLO AT 260%* 10	DLO AT 260%* 40	G + A AT 14.25%* 1	G + A AT 14.25%* 10	G + A AT 14.25%* 40	TOTAL DOLLARS 1	TOTAL DOLLARS 10	TOTAL DOLLARS 40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING LAMCO SEALOL	~~HRLY~~ SAL	6.0 4.5	1.0 .9	.5 .7	6.96	41.76 31.32	6.96 6.24	3.48 4.37	108.53 31.43	18.10 16.22	9.05 12.66	21.42 16.07	3.57 3.20	1.79 2.50	157.39 128.72	28.63 25.66	14.32 20.03
3. TOOLING	HRLY SAL				←	—	NO	TOOLING	—	—	→						
4. RAWSTOCK	HRLY SAL	—	—	—	—	40.50	27.00	24.30	—	—	—	5.77	3.85	3.46	46.27	30.85	27.76
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	25.0	15.0	13.0	12.00	300.00	180.00	156.00	—	—	—	42.75	25.65	22.23	342.75	205.65	178.23
7. ~~WELDING~~ COML PROD 48817 SHAFT RIDER SEAL ASSY	~~HRLY~~ ~~SAL~~	(REF: $186.90	SEALOL LOTS	P.O. 108959) OF 12		325.00	186.90	140.00	—	—	—	46.31	26.63	20.00	371.31	213.53	160.00
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION	HRLY SAL																
12. INSPECTION, REC LAMCO AND SEALOL	HRLY SAL	1.0 1.6	1.0 .3	1.0 .3	4.87 6.96	4.87 6.96	4.87 2.09	4.87 2.09	12.66 18.10	12.66 5.43	12.66 5.43	2.50 3.57	2.50 1.07	2.50 1.07	20.03 28.63	20.03 8.59	20.03 8.59
13. ~~INCOMING~~ INSPECTION, SOURCE (LAMCO)	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
14. SHIPPING LAMCO SEALOL	~~HRLY~~ ~~SAL~~	— —	— —	— —	— —	4.00 8.00	3.00 6.00	2.00 4.00	— —	— —	— —	.57 1.14	.43 .86	.29 .57	4.57 9.14	3.43 6.86	2.29 4.57
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						769.37	428.63	345.79							1139.54	525.53	453.04

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

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OPERATION

ITEM NO. 18

PN 1136930

/ 11-5-69

FUEL

LOW COST TURBOPUMP STUDY

UNIT COST (BASE CASE)

COST ANALYSIS PARAGON

NAME ROTOR, TURBINE #1

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	696	10490	1392	696	27144	3619	1810	5356	714	357	42940	5725	2863
3. TOOLING	HRLY SAL	—	—	—	—	105...			—	—	—	14963	—	—	119963	—	—
4. ~~RAWSTOCK~~ FORGING	~~HRLY SAL~~	—	—	—	—	75000	52500	47500	—	—	—	10698	7481	6769	85698	59981	54269
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING LATHE MILL DRILL	HRLY SAL	60.0 25.0 12.0	47.9 20.1 8.6	43.7 17.9 7.6	1195	115915	91591	82652	—	—	—	16518	13052	11778	132436	104643	94430
7. ~~[illegible]~~ PANTOGRAPH CUTTERS BENCH	HRLY SAL	125.0 10.0 60.0	98.6 7.9 47.3	89.1 7.1 42.8	915	178425	140979	127255	—	—	—	25426	20090	18134	203851	161069	145389
8. ~~[illegible]~~ VENDOR INSPECTION	HRLY SAL	15.0	11.9	10.7	1130	16950	13430	12093	—	—	—	2415	1914	1723	19365	15344	13816
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE	~~HRLY~~ SAL	15.0	7.5	5.0	696	10400	5220	3480	27040	13572	9048	5335	2678	1785	42775	21470	14313
12. INSPECTION, REC	HRLY SAL	2.0 3.0	1.0 .5	1.0 .5	487 696	974 2088	487 348	487 348	2532 5429	1266 905	1266 905	1571	428	428	12534	3434	3434
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	~~HRLY SAL~~	—	—	—	—	5000	4000	4000	—	—	—	713	570	570	5713	4570	4570
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						415192	309942	278511			TOOLING	119963			545302	376236	333094

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *

INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

OPERATION
ITEM NO. 19
PN 1136931

'11-5-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS *PARAGON*

NAME ROTOR, TURBINE #2

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.19	3.57	429.40	57.25	28.63
3. TOOLING	HRLY SAL	—	—	—	—	1050.00	—	—	—	—	—	149.63	—	—	1199.63	—	—
4. RAWSTOCK	HRLY SAL																
5. FORGINGS	~~HRLY~~ ~~SAL~~	—	—	—	—	750.00	525.00	475.00	—	—	—	106.88	74.81	67.69	856.88	599.81	542.69
6. MACHINING LATHE MILL DRILL	~~HRLY~~ ~~SAL~~	60.0 25.0 12.0	47.9 20.1 8.6	43.7 17.9 7.6	11.95	1159.15	915.91	826.52	—	—	—	165.18	130.52	117.78	1324.36	1046.43	944.30
7. PANTOGRAPH CUTTERS BENCH	~~HRLY~~ ~~SAL~~	135.0 10.0 65.0	97.0 7.2 46.7	87.9 6.5 42.3	9.15	1922.44	1509.79	1367.55	—	—	—	273.95	215.15	194.88	2196.39	1724.94	1562.43
8. VENDOR INSPECTION	~~HRLY~~ ~~SAL~~	15.0	11.9	10.7	11.30	169.50	134.30	120.93	—	—	—	24.15	19.14	17.23	193.65	153.44	138.16
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE	~~HRLY~~ SAL	15.0	7.5	5.0	6.96	104.00	52.20	34.80	270.40	135.72	90.48	53.35	26.78	17.95	427.75	214.70	143.13
12. INSPECTION, REC	HRLY SAL	2.0 3.0	1.0 .5	1.0 .5	4.87 6.96	9.74 20.88	4.87 3.48	4.87 3.48	25.32 54.27	12.66 9.05	12.66 9.05	15.71	4.28	4.28	125.24	34.34	34.34
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	~~HRLY~~ ~~SAL~~	—	—	—	—	50.00	40.00	40.00	—	—	—	7.13	5.70	5.70	57.13	45.70	45.70
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						4290.11	3199.47	2880.11			TOOLING		1199.63		5610.50	3876.[illegible]	[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

/ 10-30-69

OPERATION
ITEM NO. 20
PN 1136932

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME BOLT, TURBINE ROTOR
UNIT QUANTITY 6 ea

Item		MAN HOURS 1	MAN HOURS 10	MAN HOURS 40	RATE PER HR	NET DOLLARS 1	NET DOLLARS 10	NET DOLLARS 40	DLO AT 260% * 1	DLO AT 260% * 10	DLO AT 260% * 40	G + A AT 14.25% * 1	G + A AT 14.25% * 10	G + A AT 14.25% * 40	TOTAL DOLLARS 1	TOTAL DOLLARS 10	TOTAL DOLLARS 40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.0	1.0	.5	696	4176	696	348	10858	1810	905	2142	357	179	15939	2863	1432
3. TOOLING	HRLY SAL			NONE													
4. RAWSTOCK	HRLY SAL	—	—	—	—	3600	2400	2160	—	—	—	513	342	308	4113	2742	2468
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	15.0	8.50	7.0	1200	18000	10200	8400	—	—	—	2565	1454	1197	20560	11654	9597
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	487	244	244	244	634	634	634	125	125	125	1003	1003	1003
	SAL	.5	.15	.15	696	348	104	104	905	270	270	179	53	53	1432	421	421
12. INSPECTION SOURCE	~~HRLY~~ SAL	2.0	1.5	1.0	696	1392	1044	696	3619	2714	1810	714	536	357	5725	4294	2863
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	360	204	168	—	—	—	51	29	24	411	233	192
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST X 6ea						23120	14896	12120							49183	23216	17988

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

EWSULLIVAN X7872

OPERATION

ITEM NO. 21

PN 1136993

11-6-69

FUEL

LOW COST TURBOPUMP STUDY

UNIT COST (BASE CASE)

COST ANALYSIS (PARAGON)

NAME VANE, STATOR

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	10440	1392	696	27144	3619	1810	5356	714	357	42940	5725	2863
3. TOOLING	HRLY SAL	—	—	—	—	105000	—	—	—	—	—	14963	—	—	119963	—	—
4. RAWSTOCK	HRLY SAL																
5. ~~CASTINGS OR~~ FORGINGS	~~HRLY~~ ~~SAL~~	—	—	—	—	100000	70000	62500	—	—	—	14250	9975	8906	114250	79975	71406
6. MACHINING TURN SHROUD / TURN STATOR / TURN COMPLETE AFTER BRAZE	~~HRLY~~ ~~SAL~~	20.0 / 10.0 / 25.0	15.8 / 7.9 / 19.7	14.1 / 7.1 / 17.6	1195	65725	51848	46400	—	—	—	9366	7388	6612	75091	59236	53012
7. ~~WELDING~~ PANTOGRAPH CUTTERS	~~HRLY~~ ~~SAL~~	90.0 / 8.0	71.0 / 6.3	63.5 / 5.6	915	89670	70737	63305	—	—	—	12778	10080	9021	102448	80817	72326
8. ~~[illegible]~~ MISC. MILLING / DRILL ALL HOLES	~~HRLY~~ ~~SAL~~	12.0 / 25.0	9.5 / 19.7	8.5 / 17.6	1195	44215	34879	31215	—	—	—	6301	4970	4448	50516	39849	35663
9. ~~DEBURRING~~ BENCH / DEBURR + HAND FIN ASSY	~~HRLY~~ ~~SAL~~	50.0 / 4.0	39.4 / 3.2	35.3 / 2.8	915	49410	38978	34882	—	—	—	7041	5554	4971	56451	44532	39853
10. ~~Q C PLANNING~~ INSPECTION (VENDOR)	~~HRLY~~ ~~SAL~~	12.0	9.5	8.5	11.30	13560	10697	9573	—	—	—	1932	1524	1364	15492	12221	9709
11. INSPECTION, SOURCE	~~HRLY~~ SAL	15.0	7.5	5.0	696	10400	5220	3480	27040	13572	9048	5335	2678	1785	42775	21470	14313
12. INSPECTION, REC	HRLY SAL	2.0 / 3.0	1.0 / .5	1.0 / .5	487 / 696	974 / 2088	487 / 348	487 / 348	2532 / 5429	1266 / 905	1266 / 905	1571	428	427	12534	3484	3484
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	~~HRLY~~ ~~SAL~~	—	—	—	—	5000	4000	4001	—	—	—	713	570	570	5713	4570	4570
15. OUTSIDE PRODUCTION BRAZING / HT. TREAT	~~HRLY~~ ~~SAL~~					6500 / 6000	5129 / 4733	4589 / 4236	—	—	—	1731	1405	1253	14281	10002	8951
16.	HRLY SAL																
TOTAL UNIT COST						403932	298447	265711			TOOLING	119963			532491	361831	31100

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *

INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

10-31-69

OPERATION
ITEM NO. 22
PN 1136901

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME RING, ORIFICE-LOW PRESSURE

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY / SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	.9	.7	6.96	31.32	6.24	4.87	81.43	16.22	12.66	16.07	3.20	2.50	128.22	25.66	20.03
3. TOOLING	HRLY / SAL			NO TOOLING													
4. RAWSTOCK	HRLY / SAL	—	—	—	—	36.00	24.00	21.60	—	—	—	5.13	3.42	3.08	41.13	27.42	24.68
5. CASTINGS OR FORGINGS	HRLY / SAL																
6. MACHINING	HRLY / SAL	10.0	5.0	3.5	12.00	120.00	60.00	42.00	—	—	—	17.10	8.55	5.99	137.10	68.55	47.99
7. WELDING	HRLY / SAL																
8. ASSY & FAB QE	HRLY / SAL																
9. CLEANING	HRLY / SAL																
10. Q C PLANNING	HRLY / SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	.5	.15	.15	6.96	3.48	1.04	1.04	9.05	2.70	2.70	1.79	.53	.53	14.32	4.27	4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.63	17.19
13. INSIDE LIAISON	HRLY / SAL																
14. SHIPPING	HRLY / SAL	—	—	—	—	2.00	1.50	1.50	—	—	—	.27	.21	.21	2.27	1.71	1.71
15.	HRLY / SAL																
16.	HRLY / SAL														362.32	160.26	125.90
TOTAL UNIT COST						202.20	100.79	77.55									

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

110-31-69

OPERATION
ITEM NO. 23
PN 1136902

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME NUT, RING ORIFICE - LOW PRESSURE

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	SAL	4.5	.9	.7	6 96	31 32	6 24	4 87	81 43	16 22	12 66	16 07	3 20	2 50	128 82	25 06	20 03
3. TOOLING	HRLY SAL	—	—	—	—	150 00			—	—	—	21 33	—	—	171 33	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	34 50	23 00	20 70	—	—	—	4 92	3 28	2 95	39 42	26 27	23 65
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	12.0	7.5	6.0	12.00	144 00	90 00	72 00	—	—	—	20 52	12 83	10 26	164 52	102 83	82 26
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4 87	2 44	2 44	2 44	6 34	6 34	6 34	1 25	1 25	1 25	10 03	10 03	10 03
	SAL	.5	.15	.15	6 96	3 48	1 04	1 04	9 05	2 70	2 70	1 79	53	53	14 32	4 27	4 27
12. INSPECTION, SOURCE	SAL	1.0	.8	.6	6 96	6 96	5 57	4 18	18 10	14 48	10 87	3 57	2 57	2 14	28 63	22 62	17 19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	2 00	1 50	1 00	—	—	—	29	21	14	2 29	1 71	1 14
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						224 70	129 79	106 23					TOOLING	171 33	388 03	193 44	158 [illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN 7872

384

✓10-31-69

OPERATION

ITEM NO. 27

PN 1136904

FUEL

LOW COST TURBOPUMP STUDY

UNIT COST (BASE CASE)

COST ANALYSIS LAMCO INDUSTRIES

NAME RING, ORIFICE-HIGH PRESSURE

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	.9	.7	6.96	31.32	6.24	4.87	81.43	16.22	12.66	16.07	3.20	2.50	128.82	25.66	20.03
3. TOOLING	HRLY SAL				←	NO TOOLING	→										
4. RAWSTOCK	HRLY SAL	—	—	—	—	67.50	45.00	40.50	—	—	—	9.62	6.41	5.77	77.12	51.41	46.27
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	12.0	8.0	6.0	12.00	144.00	96.00	72.00	—	—	—	20.52	13.68	10.26	164.52	102.68	82.26
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL					2.00	1.50	1.00	—	—	—	.29	.21	.14	2.29	1.71	1.14
15.	HRLY SAL																
16.	HRLY SAL														425.73	218.38	181.19
TOTAL UNIT COST						257.70	157.79	126.03									

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *

INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

OPERATION
ITEM NO. 2B
PN 1136905

10-31-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME NUT, RING ORIFICE-HIGH PRESSURE

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.0	1.0	.5	6.96	41.76	6.96	3.48	108.59	18.10	9.05	21.42	3.57	1.79	159.39	28.63	14.32
3. TOOLING	HRLY SAL	—	—	—	—	450.00	—	—	—	—	—	64.13	—	—	514.13	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	156.00	104.00	93.60	—	—	—	22.23	14.82	13.34	178.23	118.82	106.94
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	20.0	12.0	10.0	12.00	240.00	144.00	120.00	—	—	—	34.20	20.52	17.10	274.20	164.52	137.10
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 6.96	4.87 2.09	4.87 2.09	12.66 18.10	12.66 5.43	12.66 5.43	2.50 3.57	2.50 1.07	2.50 1.07	20.03 28.63	20.03 8.57	20.03 8.57
12. INSPECTION, SOURCE	~~HRLY~~ SAL	2.0	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL					4.80	2.88	2.40	—	—	—	.62	.41	.34	5.42	3.29	2.74
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						468.31	275.84	233.40					TOOLING	514.13	723.21	386.[illegible]	308.[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

386

OPERATION

ITEM NO. 29

PN 1136906

10-31-69

FUEL

LOW COST TURBOPUMP STUDY

UNIT COST (BASE CASE)

COST ANALYSIS LAMCO

NAME VANE, DIFFUSER-PUMP

NAME		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.14	3.57	429.40	57.25	28.63
3. TOOLING	HRLY SAL			←	←	←	1250.00	→	→	→	→	173.12			1428.12		
4. RAWSTOCK	HRLY SAL	—	—	—	—	276.00	184.00	165.60	—	—	—	39.33	26.22	23.60	315.33	210.22	189.20
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	100.0	75.0	60.0	12.00	1200.00	900.00	720.00	—	—	—	171.00	128.25	102.60	1371.00	1028.25	822.60
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 6.96	4.87 2.09	4.87 2.09	12.66 18.10	12.66 5.43	12.66 5.43	2.50 3.57	2.50 1.07	2.50 1.07	20.03 28.63	20.03 8.59	20.03 8.59
12. INSPECTION SOURCE	~~HRLY~~ SAL	6.0	5.0	3.5	6.96	41.76	34.80	24.36	108.58	90.48	63.34	21.42	17.85	12.50	171.76	143.13	100.20
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	30.00	18.00	14.00	—	—	—	4.28	2.57	2.00	34.28	20.57	16.00
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						1663.77	1157.63	937.78					TOOLING	1428.12	2370.43	1487.04	1175.28

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

OPERATION

ITEM NO. 30

PN 1136907

/ 11-6-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS (PARAGON)

NAME IMPELLER, PUMP

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	20.0	3.0	1.5	6.96	139.20	20.88	10.44	361.92	54.29	27.14	71.41	10.71	5.36	572.53	85.88	42.94
3. TOOLING	HRLY SAL					950.00						135.375			1085.375		
4. ~~RAWSTOCK~~ TURN FOR GENERATOR TURN FOR BACK RIBS FINISH TURN & CONTOUR	~~HRLY~~ ~~SAL~~	35.0 15.0 15.0	27.6 11.8 19.7	24.8 10.6 17.7	11.95	896.25	707.59	636.05	—	—	—	127.72	100.83	90.64	1023.97	808.42	726.69
5. ~~SUBCONTRACTOR~~ FORGINGS	HRLY ~~SAL~~	—	—	—	—	1400.00	980.00	875.00	—	—	—	199.50	139.65	124.69	1599.50	1119.65	999.69
6. ~~MACHINING~~ VANE GENERATION / DUPN CUTTERS	HRLY SAL	300.0 25.0	236.9 19.7	212.9 17.7	7.95	3233.75	2553.05	2294.93	—	—	—	460.81	363.81	327.03	3694.56	2916.86	2621.96
7. ~~WELDING~~ MILL BACK VANES MILL CLUTCH LUGS	~~HRLY~~ ~~SAL~~	50.0 15.0	39.5 11.8	35.5 10.6	11.95	776.75	612.24	551.24	—	—	—	110.69	87.39	78.55	887.44	700.63	627.79
8. ~~ASSY & CAB QE~~ BENCH SET UP + CUT SAMPLE TRACK	~~HRLY~~ ~~SAL~~	200.0 150.0	157.9 118.4	146.9 106.5	9.15 9.50	1830.00 1425.00	1444.79 1125.04	1248.71 1011.77	—	—	—	463.37	366.91	329.17	3718.84	2936.74	2639.18
9. ~~CLEANING~~ DRILL HOLES & TAP TRIM VANES	~~HRLY~~ SAL	15.0 20.0	11.8 15.8	10.6 14.2	11.95	418.25	330.21	296.82	—	—	—	59.60	47.05	42.30	477.85	377.26	339.12
10. ~~Q.C. RECEIVING~~ VENDOR INSPECTION	~~HRLY~~ SAL	50.0	39.5	35.5	11.30	565.00	446.07	400.97	—	—	—	80.51	63.56	57.14	645.51	509.63	458.11
11. INSPECTION, SOURCE	~~HRLY~~ SAL	45.0	30.0	20.0	6.96	313.20	208.80	139.20	814.32	542.88	361.92	160.07	107.11	71.41	1288.19	858.79	572.53
12. INSPECTION, REC	HRLY SAL	2.0 3.0	1.0 .5	1.0 .5	4.87 6.96	9.74 20.88	4.87 3.48	4.87 3.48	25.32 54.29	12.66 9.05	12.66 9.05	15.71	4.28	4.28	125.34	34.34	34.34
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	~~HRLY~~ ~~SAL~~	—	—	—	—	90.00	70.00	65.00	—	—	—	12.83	9.98	9.26	102.83	79.98	74.26
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						11118.02	8508.02	7588.00				TOOLING	1085.375		[illegible]	[illegible]	[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *

INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

388

OPERATION
ITEM NO. 31
PN 1136908

11-6-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS (PARAGON)

NAME INDUCER, PUMP

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.14	3.57	429.40	57.25	28.63
3. TOOLING	HRLY SAL	—	—	—	—	4200.00	—	—	—	—		578.50	—		4778.50	—	—
4. RAWSTOCK	HRLY SAL																
5. ~~CASTINGS OR~~ FORGINGS	HRLY SAL	—	—	—	—	1000.00	700.00	625.00	—	—	—	142.50	99.75	89.06	1142.50	799.75	714.06
6. MACHINING TURN FOR GEN / TURN FOR SPLINE / FINISH TURN + CONTOUR	~~HRLY~~ ~~SAL~~	60.0 20.0 25.0	47.4 15.8 19.7	42.1 14.0 17.5	11.95	1254.75	999.54	880.01	—	—	—	178.80	142.43	125.40	1433.55	1141.97	1005.41
7. ~~WELDING~~ ROUGH GEN / VANE GENERATION/DUP CUTTERS	~~HRLY~~ ~~SAL~~	100.0 125.0 15.0	78.9 98.7 11.8	70.1 87.7 10.5	9.95	2388.00	1885.16	1388.00	—	—	—	340.29	268.64	197.79	2728.29	2153.80	1585.79
8. ~~ASSY & FAB QE~~ KEYS + TOOLING HOLE / TRIM PARTIALS	~~HRLY~~ ~~SAL~~	5.0 20.0	3.9 15.8	3.5 14.0	11.95	298.75	235.84	209.53	—	—	—	42.57	33.61	29.86	341.32	269.45	239.39
9. ~~CLEANING~~ SET UP & CUT SAMPLE TRACK	~~HRLY~~ SAL	100.0	10 76.9	2.5 70.1	9.50	750.00	749.96	666.23	—	—	—	135.38	106.87	94.94	1085.38	856.83	761.22
10. ~~Q.C. CLEANING~~ BENCH	~~HRLY~~ ~~SAL~~	80.0	63.2	56.1	9.15	732.00	577.86	513.39	—	—	—	104.31	82.35	73.16	836.31	660.21	586.55
11. INSPECTION, SOURCE	~~HRLY~~ SAL	30.0	10.0	7.0	6.96	208.80	69.60	48.72	542.88	180.96	126.67	107.11	35.70	24.99	858.79	286.26	200.38
12. INSPECTION, REC	HRLY SAL	2.0 3.0	1.0 .5	1.0 .5	4.87 6.96	9.74 20.88	4.87 3.48	4.87 3.48	25.32 54.29	12.66 9.05	12.66 9.05	15.71	4.23	4.23	125.34	34.39	34.39
13. ~~INSIDE LIAISON~~ VENDOR INSPECTION	~~HRLY~~ ~~SAL~~	25.0	19.7	17.5	11.30	282.50	223.01	196.13	—	—	—	40.26	31.78	28.23	322.76	254.79	226.36
14. SHIPPING	HRLY SAL	—	—	—	—	50.00	40.00	40.00	—	—	—	7.13	5.70	5.70	57.13	45.70	45.70
15. OUTSIDE PRODUCTION THREAD GRIND & SPLINE	~~HRLY~~ ~~SAL~~	—	—	—	—	125.00 100.00	93.68 79.44	87.67 70.14	—	—	—	32.06	25.31	22.41	257.06	202.93	180.30
16.	HRLY SAL																
TOTAL UNIT COST						7524.82	5680.86	4742.18				TOOLING INC	4778.50		9619.23	6763.23	5208.13

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTACES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

OPERATION
ITEM NO. 32
PN 1136909

/10-31-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO INDUSTRIES

NAME NUT ASSY. IMPELLER RETAINING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.0	1.0	.5	6 96	41 76	6 96	3 48	108 58	18 10	9 05	21 42	3 57	1 79	159 39	28 63	14 32
3. TOOLING	HRLY SAL	—	—	—	—	150 00	—	—	—	—	—	21 38	—	—	171 38	—	—
4. RAWSTOCK	HRLY SAL	—	—	—	—	6 60	4 40	3 96	—	—	—	94	63	56	7 54	5 03	4 52
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	9.0	5.5	4.0	12 00	108 00	66 00	48 00	—	—	—	15 39	9 41	6 84	123 39	75 41	54 84
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION REC.	HRLY	.5	.5	.5	4 87	2 44	2 44	2 44	6 34	6 34	6 34	1 25	1 25	1 25	10 03	10 03	10 03
	SAL	.5	.15	.15	6 96	3 48	1 04	1 04	9 05	2 70	2 70	1 79	53	53	14 32	4 27	4 27
12. INSPECTION SOURCE	~~HRLY~~ SAL	1.0	1.0	1.0	6 96	6 96	6 96	6 96	18 10	18 10	18 00	3 57	3 57	3 57	28 63	28 63	28 63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	2 00	1 50	1 00	—	—	—	29	21	14	2 29	1 71	1 14
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						171 24	89 30	66 88					TOOLING	171 33	349 23	153 71	117 25

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

390

OPERATION
ITEM NO. 33
PN 1136934

✓ 11-3-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO (MACH) PICCO INDUSTRIES (CASTING)

NAME MANIFOLD ASSY, TURBINE INLET

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING PICCO	~~HRLY~~	30.0	5.0	3.0	6.96	208.80	34.80	20.88	542.80	90.48	54.29	107.10	17.85	10.71	858.70	143.13	85.88
LAMCO	SAL	30.0	5.0	3.0		208.80	34.80	20.88	542.80	90.48	54.29	107.10	17.85	10.71	858.70	143.13	85.88
3. TOOLING PICCO INDUSTRIES	~~HRLY~~	—	—	—	—	15,000	—	—	—	—	—	2137.50	—	—	17137.50	—	—
LAMCO	~~SAL~~	—	—	—	—	1800	—	—	—	—	—	256.50	—	—	2056.50	—	—
4. RAWSTOCK LAMCO	~~HRLY SAL~~	—	—	—	—	1440.00	960.00	864.00	—	—	—	205.20	136.80	123.12	1645.20	1096.80	987.12
5. CASTINGS PICCO INDUSTRIES	~~HRLY SAL~~	429	143	121	14.00	6000.00	2000.00	1700.00	—	—	—	855.00	285.00	242.00	6855.00	2285.00	1942.00
6. MACHINING (LAMCO)	HRLY SAL	154.0	95.0	75.0	12.00	1848.00	1140.00	900.00	—	—	—	263.00	162.45	128.25	2111.00	1302.45	1028.25
7. WELDING (LAMCO)	HRLY SAL	196.0	125.0	125.0	12.00	2352.00	1500.00	1500.00	—	—	—	335.16	213.75	213.75	2687.16	1775.00	1775.00
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE PICCO	~~HRLY~~	30.0	10.0	8.0		208.80	69.60	55.68	542.88	180.96	144.77	107.11	35.70	28.56	858.79	286.26	229.01
LAMCO	SAL	40.0	15.0	10.0	6.96	278.40	104.40	69.60	723.84	271.44	180.96	142.82	53.56	35.70	1145.06	429.40	286.26
12. INSPECTION, REC. (PICO)	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	2.0	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING PICO	~~HRLY~~	—	—	—	—	60.00	55.00	50.00	—	—	—	8.55	7.84	7.13	68.55	62.84	57.13
LAMCO	~~SAL~~					84.00	50.00	45.00				11.97	7.13	6.41	95.97	57.13	51.41
15. INSPECTION, REC. (LAMCO)	HRLY	2.0	2.0	2.0	4.87	9.74	9.74	9.74	25.32	25.32	25.32	5.00	5.00	5.00	40.06	40.06	40.06
	SAL	4.0	3.0	2.0	6.96	27.84	20.88	13.92	72.38	54.29	36.19	14.28	10.71	7.14	114.50	85.88	57.25
16.	HRLY SAL																
TOTAL UNIT COST						12742.74	5492.10	5259.10						TOOLING 19194.00	17405.72	7760.95	

6663.91

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

✓10-4-69

OPERATION
ITEM NO. 34
PN 1136910

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS LAMCO (MACH) PERFECTO CAST (CASTING)

NAME VOLUTE, PUMP HOUSING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING PERFECTO LAMCO	~~HRLY~~ SAL	15.0 20.0	2.0 3.0	1.0 1.5	6.96	104.40 135.20	13.92 20.88	6.96 10.44	271.44 351.52	36.19 54.29	18.10 27.14	53.56 69.36	7.14 10.71	3.57 5.36	429.40 556.03	57.25 85.88	28.63 42.94
3. TOOLING PERFECTO CAST LAMCO	~~HRLY~~ ~~SAL~~	— —	— —	— —	— —	4000.00 5750.00	— —	— —	— —	—	—	575.00 814.44	— —	— —	4575.00 6564.44	— —	— —
4. RAWSTOCK	HRLY SAL																
5. CASTINGS ~~OR FORGING~~ PERFECTO CAST	HRLY SAL	114.0	98.0	87.0	14.00	1600.00	1375.00	1250.00	—	—	—	228.00	195.94	178.13	1828.00	1570.94	1428.13
6. MACHINING (LAMCO)	HRLY SAL	140.0	80.0	70.0	12.00	1680.00	960.00	840.00	—	—	—	239.40	136.80	119.70	1919.40	1096.80	957.70
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE PERFECTO LAMCO	~~HRLY~~ SAL	8.0 15.0	5.0 7.5	5.0 5.0	6.96	55.68 104.00	34.80 52.20	34.80 34.80	144.77 270.40	90.48 135.72	90.48 90.48	28.56 53.35	17.85 26.78	17.85 17.85	229.01 427.75	143.13 214.70	143.13 143.13
12. INSPECTION, REC (PERFECTO)	HRLY SAL	.5 2.0	.5 1.5	.5 1.0	4.87 6.96	2.44 13.92	2.44 10.44	2.44 6.96	6.34 36.19	6.34 27.14	6.34 18.10	1.25 7.14	1.25 5.36	1.25 3.57	10.03 57.25	10.03 42.94	10.03 28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING PERFECTO LAMCO	~~HRLY~~ ~~SAL~~	—	—	—	—	30.00 50.00	25.00 40.00	25.00 40.00	—	—	—	4.28 7.13	3.56 5.70	3.56 5.70	34.28 57.13	28.56 45.70	28.56 45.70
15. INSPECTION, REC (LAMCO)	HRLY SAL	1.0 2.0	1.0 1.5	1.0 1.0	4.87 6.96	4.87 13.92	4.87 10.44	4.87 6.96	12.66 36.19	12.66 27.14	12.66 18.10	2.50 7.14	2.50 5.36	2.50 3.57	20.03 57.25	20.03 42.94	20.03 28.63
16.	HRLY SAL																
TOTAL UNIT COST						3794.43	2549.99	2263.23			TOOLING	5231.94			5225.[illegible]	3358.[illegible]	2987.[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

392

OPERATION
ITEM NO. (*) ASSEMBLE TURBOPUMP
PN 1136900

11-4-69

FUEL
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME TURBOPUMP ASSEMBLY

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	1.0	1.0	6 96	20 88	6 96	6 96	54 29	18 10	18 10	10 71	3 57	3 57	85 88	28 63	28 63
3. TOOLING (OP) ROTOR LOCKS (1 EACH END) LEAK CHECK KIT (4 PLATES)	~~HRLY~~ ~~SAL~~					400 00 400 00											
4. ~~RAW STOCK~~ TOOLING (OP) SHAFT POSITIONING FIXTURE SPANNER WRENCHES (3)	~~HRLY~~ ~~SAL~~					300 00 600 00						313 50	—	—	2513 50	—	—
5. ~~CASTINGS OR FORGINGS~~ TOOLING (OP) BUILD/UP STAND	~~HRLY~~ ~~SAL~~					500 00											
6. MACHINING	HRLY SAL																
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL	25.0	25.0	25.0	6 96	174 00	174 00	174 00	452 40	452 40	452 40	89 26	89 26	89 26	715 66	715 66	715 66
9. CLEANING	HRLY SAL	16.0 3.0	10.0 2.0	8.0 1.6	4.87 6 96	77 92 20 88	48 70 13 92	38 96 11 14	202 59 54 29	126 62 36 19	101 30 28 96	39 92 10 71	24 98 7 14	19 98 5 71	320 43 85 88	200 30 57 25	160 22 45 80
10. ~~[illegible]~~ (LOG BOOK) QA DOCUMENT CONTROL	~~HRLY~~ SAL	30.0	22.0	15.0	6 96	208 80	153 12	104 40	542 88	398 11	271 44	107 11	78 55	53 51	858 79	629 78	429 05
11. INSPECTION	HRLY SAL		+10% 33	+10% 26.4			161	129		419	335		83	66		663	530
12. INSPECTION, ASSY	HRLY SAL	48.0 13.0	30.0 8.0 3.3	24.0 6.5 7.3	4.87 6 96	233 76 90 48	146 10 55 68 61	116 88 45 24 50	607 78 235 25	379 86 144 77 159	303 89 117 62 130	119 92 46 42	74 95 28 56	59 96 23 21 26	961 46 372 15	749 99 229 01 251	480 73 186 07 ~~206~~
13. INSIDE LIAISON	~~HRLY~~ SAL	60.0	38.0	30.0	6 96	417 60	264 48	208 80	1085 76	687 65	542 88	214 23	135 68	107 11	1717 52	1087 81	858 79
14. ~~[illegible]~~ PRODUCTION CONTROL	~~HRLY~~ SAL	12.0	12.0	12.0	6.96	83 52	83 52 536	83 52 429	217 15	217 15 1394	217 15 1115	42 85	42 35 275	42 35 220	343 52	343 52 2205	343 52 1764
15. ASSEMBLY LABOR	HRLY SAL	~~176~~ 160.0 48.0	110 100.0 30.0 33	88 80.0 24.0 26.4	4.87 6.96	779 20 334 08	487 00 208 80 230	387 60 167 04 184	2025 92 868 61	1266 20 542 88 598	1012 96 434 39 478	399 73 171 38	249 83 107 11 119	199 86 85 69 94	3204 85 1374 07	2003 03 858 79 946	1602 42 687 03 756
16. SHOP PLANNING (MFG. ENG.)	~~HRLY~~ SAL	40.0	4.0	2.0	6.96	278 40	27 84	13 92	723 84	104 00	36 19	142 82	18 79	7 14	1145 96	150 63	57 25
TOTAL UNIT COST						2719 52	1670 12	1360 46			ASSY TOOLING	2513 50			11185 34	7053 93	5575 31
													ALT #1 →			7281 +3.2	5896 +5.2

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

APPENDIX I

BASE CASE OXIDIZER TURBOPUMP COST ANALYSIS

11-17-69

OPERATION
ITEM NO. 1
PN 1137010

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME HOUSING, BEARING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING PERFECTO CAST / LAMCO	~~HRLY~~ SAL	9.0 15.0	1.0 7.5	.7 5.0	6.96 6.96	62.64 104.00	6.96 52.20	4.87 34.80	162.86 270.40	18.10 135.72	12.66 90.48	32.13 53.35	3.57 26.78	2.50 17.85	257.63 427.75	28.63 214.70	20.83 143.13
3. TOOLING PERFECTO CAST / LAMCO	HRLY SAL	— —	— —	— —	— —	1100.00 550.00	— —	— —	— —		— —	156.75 121.13	— —	— —	1256.75 471.13	— —	— —
4. RAWSTOCK	HRLY SAL																
5. CASTINGS PERFECTO CAST	HRLY SAL	71.4	50.0	44.6	14.00	1000.00	700.00	625.00	—	—	—	142.50	99.75	89.06	1142.50	799.75	714.06
6. MACHINING TURN COMPLETE / DRILL & TAP	~~HRLY~~ ~~SAL~~	40.0 40.0	30.8 30.8	26.4 26.4	11.95	478.00 478.00	368.06 368.06	315.48 315.48	—	—	—	136.23	104.90	89.91	1092.23	841.02	720.87
7. MISC MILLING	~~HRLY~~ ~~SAL~~	16.0	12.3	10.6	11.95	191.20	147.22	126.19	—	—	—	27.25	20.98	17.98	218.45	168.20	144.17
8. BENCH / INSPECT	~~HRLY~~ ~~SAL~~	20.0 12.0	15.4 9.2	13.2 7.9	9.15 11.30	183.00 135.60	140.91 104.41	120.78 89.50	—	—	—	45.40	34.96	29.96	364.00	280.28	240.24
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION SOURCE PERFECTO / LAMCO	~~HRLY~~ SAL	4.5 9.0	3.0 7.5	2.7 5.0	6.96	31.32 62.64	20.88 52.20	18.79 34.80	81.43 162.86	54.29 135.72	48.85 90.48	16.07 32.13	10.71 26.78	9.64 17.85	128.82 257.63	85.88 214.70	77.28 143.13
12. INSPECTION REC (PERFECTO)	HRLY SAL	.5 2	.5 1.5	.5 1.0	4.87 6.96	2.44 13.92	2.44 10.44	2.44 6.96	6.34 36.19	6.34 27.14	6.34 18.10	125.00 7.14	125.00 5.36	125.00 3.57	10.03 57.25	10.03 42.94	10.03 28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING PERFECTO / PARAGON	~~HRLY~~ ~~SAL~~	—	—	—	—	20.00 30.00	14.00 24.00	12.00 18.00	—	—	—	7.13	5.42	4.28	57.13	43.42	34.28
15. INSPECTION, REC LAMCO	HRLY SAL	1.0 2.0	1.0 1.5	1.0 1.0	4.87 6.96	4.87 13.92	4.87 10.44	4.87 6.96	12.66 36.19	12.66 27.14	12.66 18.10	2.50 7.14	2.50 5.36	2.50 3.57	20.03 57.25	20.03 42.94	20.03 28.63
16.	HRLY SAL																
TOTAL UNIT COST						2811.55	2027.89	1736.92			TOOLING	2227.88			4090.79	2792.62	[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

EW SULLIVAN X7972

396

11-17-69

OPERATION
ITEM NO. 2
PN 1137011

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME SHAFT

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	104.90	13.92	6.96	271.44	36.19	17.10	53.56	7.14	3.57	429.40	57.25	28.63
3. TOOLING	HRLY SAL																
4. RAWSTOCK	~~HRLY~~ ~~SAL~~	—	—	—	—	499.00	329.00	296.00	—	—	—	70.25	46.88	42.18	568.25	375.88	338.18
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE DRILL	~~HRLY~~ ~~SAL~~	60.0 16.0	46.2 12.3	39.6 10.6	11.95	717.00 192.20	532.09 147.99	473.22 126.85	—	—	—	129.56	99.76	85.51	1038.76	799.84	685.58
7. ~~WELDING~~ MILL SPLINES ~~MISC MILLING~~	~~HRLY~~ ~~SAL~~	40.0	30.8	26.4	11.95	478.00	363.06	315.48	—	—	—	68.12	52.95	44.96	546.12	420.51	360.44
8. ~~ASSY & FAB QL~~ BENCH INSPECT	~~HRLY~~ ~~SAL~~	10.0 9.0	7.7 6.9	6.6 5.9	9.15 11.30	91.50 145.77	70.44 112.24	60.39 96.21	—	—	—	33.71	26.03	22.32	271.08	208.73	178.92
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 6.96	4.87 2.09	4.87 2.09	12.66 18.10	12.66 5.43	12.66 5.43	2.50 3.57	2.50 1.07	2.50 1.07	20.03 28.63	20.03 8.59	20.03 8.59
12. INSPECTION SOURCE	~~HRLY~~ SAL	6.0	5.0	3.5	6.96	41.76	34.80	24.36	108.58	90.48	63.34	21.42	17.85	12.50	171.76	143.13	100.20
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	24.00	20.00	18.00	—	—	—	3.42	2.85	2.57	27.42	22.85	20.57
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						2299.46	1655.52	1424.43							3096.45	2056.81	1791.62

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

OPERATION
ITEM NO. 3 4-13
PN 1137012
90 mm

LO2 -11-18-69

LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS (ITI) REF: PO L108824 9-26-69 ($463.13 ea QUAN. OF 12)

NAME BEARING, BALL - UPPER - LOWER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	9.0	1.0	.7	6.96	62.64	6.96	4.87	162.86	18.10	12.66	32.13	3.57	2.50	257.63	28.63	20.03
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL					COST EACH 875.00	725.00	580.00									
5. CASTINGS OR FORGINGS	HRLY SAL					QUANTITIES ORDERED 3	25	90									
6. MACHINING QUANTITIES SHOWN INCLUDE SPARES	~~HRLY~~ ~~SAL~~	—	—	—	—	2625.00	1812.50	1305.00	—	—	—	374.06	258.28	185.96	2999.06	2070.78	1490.96
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE	~~HRLY~~ SAL	2.0	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
12. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 13.92	4.87 10.44	4.87 6.96	12.66 36.19	12.66 27.14	12.66 18.10	2.50 7.14	2.50 5.36	2.50 3.57	20.03 57.25	20.03 42.94	20.03 28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	75.00	50.00	40.00	—	—	—	10.69	7.13	5.70	85.69	57.13	45.70
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						2795.35	1895.21	1369.66							3476.81	2262.45	1633.88

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7972

11-19-69

OPERATION
ITEM NO. 4
PN 1137013

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE) (PN 712409-29) (REF.)
COST ANALYSIS GETTS MFG. ~~[illegible]~~ (~~EACH @ [illegible]~~)

NAME SEAL ASSY, BELLOWS-UPPER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	150	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.14	3.57	429.40	57.25	28.63
3. ~~TOOLING~~	HRLY SAL				**	QUANTITIES ORDERED 2	12	44									
4. ~~RAWSTOCK~~	HRLY SAL					COST EACH 2400.00	2000.00	1400.00									
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING GETTS MFG	HRLY SAL	—	—	—	—	4800.00	2400.00	1540.00	—	—	—	684.00	342.00	219.45	5484.00	2742.00	1768.45
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE	~~HRLY~~ SAL	2.0	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
12. INSPECTION, REC	HRLY SAL	1.0	1.0	1.0	4.87	4.87	4.87	4.87	12.66	12.66	12.66	2.50	2.50	2.50	20.03	20.03	20.03
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	30.00	25.00	20.00	—	—	—	4.28	3.56	2.85	34.28	28.56	22.85
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						4953.69	2454.23	1578.79							6024.96	2870.78	1868.59

* MIDPOINT OF EFFORT - JAN '71

** INCLUDES SPARES

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7892

OPERATION

ITEM NO. 5

PN 1137014

LO2

/11-18-69

LOW COST TURBOPUMP STUDY

UNIT COST (BASE CASE)

COST ANALYSIS (B&W MFG) [redacted]

(ROM QUOTE FROM B&W 11-20-69 - SIMILAR PART)

(FLAME PLATED 347) ~~[illegible]~~

NAME SEAL RING, RUNNING - UPPER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL	—	—	—	**	QUANTITIES 2	ORDERED 12	44	—	—	—	—	—	—	—	—	—
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	.9	.7	6.96	31.32	6.24	4.87	81.43	16.22	12.66	16.07	3.20	2.50	128.82	25.66	20.03
3. TOOLING UNION CARBIDE	HRLY ~~SAL~~	—			TOOLING SET UP	50.00 20.00	—	—	—	—	—	9.48	—	—	79.78	—	—
4. ~~RAWSTOCK~~ UNION CARBIDE FLAME PLATING (LWS .002-.004)	~~HRLY~~ ~~SAL~~	—	—	—	—	33.70 COST	24.45 EACH	17.95	—	—	—	—	—	—	—	—	—
5. ~~CASTINGS OR FORGINGS~~ OP COST FLAME PLATING	~~HRLY~~ ~~SAL~~	—	—	—	—	67.40	29.34	19.75	—	—	—	9.60	4.18	2.81	77.00	33.52	22.56
6. MACHINING TURN COMPLETE GRIND & LAP	HRLY SAL	5.0 23.0	2.2 9.9	1.3 6.0	11.95	56.50 274.85	25.73 118.37	15.45 71.07	—	—	—	47.22	20.53	12.33	378.57	164.63	98.85
7. ~~WELDING~~ BENCH INSPECT	HRLY SAL	1.0 5.0	.7 2.3	.4 1.4	9.15 11.30	9.15 56.50	5.95 25.73	3.09 15.45	—	—	—	9.36	4.51	2.64	75.01	36.19	21.18
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	10.00	4.00	3.50	—	—	—	1.43	.57	.50	11.43	4.57	4.00
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						518.60	224.41	140.84			TOOLING	74.93			723.81	301.49	198.11

* MIDPOINT OF EFFORT - JAN '71

** INCLUDES SPARES

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *

INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

399

400

OPERATION
ITEM NO. 6
PN 1137015

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

11-18-69

NAME SEAL RING, RUNNING-LOWER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL				**	QUANTITIES ORDERED 2	12	44									
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	6.0	1.0	.5	6.96	41.76	6.96	3.43	108.58	18.10	9.05	21.42	3.57	1.79	159.34	28.03	14.32
3. TOOLING UNION CARBIDE	HRLY SAL					125.00	—	—	—	—	—	17.81	—	—	142.81	—	—
4. ~~RAWSTOCK~~ UNION CARBIDE .002 TO .004 FLAME PLATING (LWS MAT.)	HRLY SAL	COST EACH 144.75	115.45	99.25		289.50	138.54	109.18	—	—	—	41.25	19.74	15.56	330.75	158.28	124.74
5. ~~CASTINGS OR FORGINGS~~	~~HRLY~~ ~~SAL~~				~~[illegible]~~												
6. MACHINING TURN COMPLETE GRIND & LAP	~~HRLY~~ ~~SAL~~	15.0 34.6	6.0 13.8	4.0 9.3	11.95	180.00 414.00	72.00 165.60	48.42 111.37	—	—	—	84.65	33.86	22.77	678.65	271.46	182.56
7. ~~WELDING~~ BENCH INSPECT	~~HRLY~~ ~~SAL~~	2.0 4.8	.8 1.9	.5 1.3	9.15 11.30	18.00 54.00	7.20 21.60	4.84 14.53	—	—	—	10.26	4.10	2.76	82.26	32.90	22.13
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 6.96	4.87 2.09	4.87 2.09	12.66 18.10	12.66 5.43	12.66 5.43	2.50 3.57	2.50 1.07	2.50 1.07	20.03 28.63	20.03 8.59	20.03 8.59
12. INSPECTION SOURCE	~~HRLY~~ SAL	2.0	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL					18.00	7.00	6.00	—	—	—	2.57	1.00	.86	20.57	8.00	6.86
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						1041.01	436.30	311.69			TOOLING	142.81			1376.55	570.83	407.86

* MIDPOINT OF EFFORT - JAN '71
** INCLUDES SPARES

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

EW SULLIVAN X7872

/ 11-19-69

OPERATION
ITEM NO. 7
PN 1137016

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME SEAL ASSY, SHAFT RIDING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL	SEALOL	COMMERCIAL	ASSY →		COST 325.00	EACH 140.00	115.00	QUANTITIES 3	ORDERED 25	90	← SEALOL COMMERCIAL ASSY ONLY					
2. PROCUREMENT PLANNING OP SEALOL	~~HRLY~~ SAL	6.0 4.5	1.0 .9	.5 .7	6.96	41.76 31.32	6.96 6.24	3.48 4.87	108.58 81.43	18.10 16.22	9.05 12.66	21.42 16.07	3.57 3.20	1.79 2.50	159.39 128.82	28.63 25.66	14.32 20.03
3. [redacted] RAW STOCK	~~HRLY~~ ~~SAL~~	—	—	—	—	40.50	27.00	24.30	—	—	—	5.77	3.85	3.46	46.27	30.85	27.76
4. [redacted] REF: COML PROD 48817 SEALOL SHAFT RIDER SEAL ASSY	HRLY SAL	REF: P.O. 102957 176.90 EA IN LOTS OF 12			2 EA REQ	975.00	350.00	258.75	—	—	—	138.94	49.88	36.87	1113.94	399.88	295.62
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE MISC MILLING	~~HRLY~~ ~~SAL~~	12.0 5.0	9.4 3.9	8.5 3.5	11.95	143.40 59.75	112.44 46.85	101.11 42.13	—	—	—	28.95	22.70	20.41	232.10	181.91	163.65
7. ~~WELDING~~ DRILL GRIND	~~HRLY~~ ~~SAL~~	3.0 3.0	2.4 2.4	2.1 2.1	11.95	35.85 35.85	28.11 28.11	25.28 25.28	—	—	—	10.22	8.01	7.20	81.92	64.23	57.76
8. ASSY & FAB QE BENCH INSPECT	~~HRLY~~ ~~SAL~~	1.0 3.0	.8 2.4	.7 2.1	9.15 11.30	9.15 33.90	7.17 26.58	6.45 23.90	—	—	—	6.13	4.81	4.32	47.18	38.56	34.67
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 6.96	4.87 2.09	4.87 2.09	12.66 18.10	12.66 5.43	12.66 5.43	2.50 3.57	2.50 1.07	2.50 1.07	20.03 28.63	20.03 8.59	20.03 8.59
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING OP SEALOL	~~HRLY~~ ~~SAL~~	—	—	—	—	4.00 8.00	3.00 6.00	2.00 4.00	—	—	—	.57 1.14	.43 .86	.29 .57	4.57 9.14	3.43 6.86	2.29 4.57
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						1437.27	620.99	532.70							1902.62	831.35	666.80

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

OPERATION
ITEM NO. 8
PN 1137017

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS GETTS MFG. (~~[illegible]~~ [redacted]
REF: PN 712409-29

11-19-69

NAME SEAL ASSY, BELLOWS-LOWER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	[redacted] SAL	15.0	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.14	3.57	427.40	57.25	28.63
3. ~~TOOLING~~	HRLY SAL				**	QUANTITIES 2	ORDERED 12	44									
4. ~~RAWSTOCK~~	HRLY SAL	—	—	—	—	COST 2200.00	EACH 1750.00	1200.00	—	—	—	[redacted]			[redacted]		
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING GETTS MFG	HRLY SAL	—	—	—	—	4400.00	1925.00	1320.00	—	—	—	627.00	274.31	188.10	5027.00	2199.31	1508.10
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE	~~HRLY~~ SAL	2.0	1.5	1.0	6.96	13.92	10.44	6.96	36.19	27.14	18.10	7.14	5.36	3.57	57.25	42.94	28.63
12. INSPECTION, REC	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 13.92	4.87 10.44	4.87 6.96	12.66 36.19	12.66 27.14	12.66 18.10	2.50 7.14	2.50 5.36	2.50 3.57	20.03 57.25	2.03 42.94	20.03 28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	30.00	25.00	20.00	—	—	—	4.28	3.56	2.85	34.28	28.56	22.85
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						4567.11	1989.67	1365.75							5625.21	2379.03	1696.87

* MIDPOINT OF EFFORT - JAN '71

** INCLUDES SPARES

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

OPERATION
ITEM NO. 9
PN 1137018

LO2 11-20-69

LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME NUT, SEAL RETAINING

		MAN HOURS 1	MAN HOURS 10	MAN HOURS 40	RATE PER HR	NET DOLLARS 1	NET DOLLARS 10	NET DOLLARS 40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL							
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	.9	.7	6.96	31.32	6.24	4.87
3. TOOLING	HRLY SAL							
4. RAWSTOCK	HRLY SAL	—	—	—	—	34.50	23.00	20.70
5. CASTINGS OR FORGINGS	HRLY SAL							
6. MACHINING TURN COMPLETE / MISC MILLING	~~HRLY~~ ~~SAL~~	6.0 / 5.0	4.6 / 3.9	4.0 / 3.3	11.95	71.70 / 59.75	55.21 / 46.51	47.32 / 39.49
7. ~~[illegible]~~ BENCH / INSPECTION	~~HRLY~~ ~~SAL~~	2.0 / 2.0	1.6 / 1.6	1.4 / 1.4	9.15 / 11.30	18.30 / 33.90	14.09 / 27.53	12.08 / 24.05
8. ASSY & FAB QE	HRLY SAL							
9. CLEANING	HRLY SAL							
10. Q C PLANNING	HRLY SAL							
11. INSPECTION, REC	HRLY SAL	.5 / .5	.5 / .15	.5 / .15	4.87 / 6.96	2.44 / 3.48	2.44 / 1.04	2.44 / 1.04
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18
13. INSIDE LIAISON	HRLY SAL							
14. SHIPPING	HRLY SAL	—	—	—	—	2.00	1.50	1.00
15.	HRLY SAL							
16.	HRLY SAL							
TOTAL UNIT COST						264.35	182.63	157.12

	DLO AT 260% * 1	DLO AT 260% * 10	DLO AT 260% * 40	G + A AT 14.25% * 1	G + A AT 14.25% * 10	G + A AT 14.25% * 40	TOTAL DOLLARS 1	TOTAL DOLLARS 10	TOTAL DOLLARS 40
1. ADVANCE QUOTES/CONSULTING									
2. PROCUREMENT PLANNING	81.43	16.22	12.66	16.07	3.20	2.50	128.82	25.66	20.03
3. TOOLING									
4. RAWSTOCK	—	—	—	4.92	3.28	2.95	39.42	26.28	23.65
5. CASTINGS OR FORGINGS									
6. MACHINING	—	—	—	18.73	14.42	12.36	150.18	115.84	99.12
7. BENCH INSPECTION	—	—	—	7.44	5.94	4.86	57.64	47.60	38.99
8. ASSY & FAB QE									
9. CLEANING									
10. Q C PLANNING									
11. INSPECTION, REC	6.34 / 9.05	6.34 / 2.70	6.34 / 2.70	1.25 / 1.79	1.25 / .53	1.25 / .53	10.03 / 14.32	10.03 / 4.27	10.03 / 4.27
12. INSPECTION, SOURCE	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.60	17.19
13. INSIDE LIAISON									
14. SHIPPING	—	—	—	.29	.21	.14	2.29	1.71	1.14
15.									
16.									
TOTAL UNIT COST							433.33	254.01	214.98

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

404

/11-20-69

OPERATION
ITEM NO. 10
PN 1137019

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

ENGINEER: ALLEN WYNNE
CIRCLE SEAL FILTER DIV ATTN: GARY RAY
QUOTED 11-24-69

NAME FILTER, SS (10 MICRON)

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL	COST 130.42	EACH 106.92	91.61		QUAN 2	TITIES 12	ORDERED 44									
2. PROCUREMENT PLANNING	SAL	3.0	.6	.5	6.96	20.88	4.18	3.48	54.29	10.87	9.05	10.71	2.14	1.79	85.88	17.19	14.32
3. TOOLING	HRLY SAL	—	—	—	—	[illegible]	—	—	—	—	—	8.55	—	—	68.55	—	—
4. RAWSTOCK BRUNSWICK CORP. "BRUNSPORE"	HRLY SAL	INCLUDED	IN	COML	COST												
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING COML PROD F4081	HRLY SAL	—	—	—	—	260.84	128.30	100.77	—	—	—	37.17	18.28	14.36	298.01	146.58	115.13
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	12.00	8.00	7.00	—	—	—	1.71	1.14	1.00	13.71	9.14	8.00
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						306.60	149.53	118.91		TOOLING	68.55				450.58	209.83	168.94

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7372

LO2

/11-21-69

OPERATION

ITEM NO. 12

PN 1137020

LOW COST TURBOPUMP STUDY

UNIT COST (BASE CASE)

COST ANALYSIS

NAME SPACER, BEARING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	.6	.5	6.96	20.88	4.18	3.48	54.29	10.87	9.05	10.71	2.14	1.79	85.88	17.19	14.32
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	70.00	47.00	43.00	—	—	—	9.98	6.70	6.13	79.98	[illegible]	49.13
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE MISC MILLING	~~HRLY~~ ~~SAL~~	17.0 10.0	13.1 7.9	11.2 7.1	11.95	203.15 119.50	156.42 74.65	134.07 84.63	—	—	—	45.98	35.78	31.16	368.63	286.85	249.86
7. ~~WELDING~~ BENCH INSPECT	~~HRLY~~ ~~SAL~~	2.0 2.0	1.6 1.6	1.4 1.4	9.15 11.30	18.30 22.60	14.49 17.90	12.96 16.01	—	—	—	5.83	4.62	4.13	46.73	37.01	33.10
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.5	1.0	.9	6.96	10.44	6.96	6.26	27.14	18.10	16.28	5.36	3.57	3.21	42.94	28.63	25.81
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL					6.00	4.32	3.84	—	—	—	.86	.62	.55	6.86	4.94	4.39
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						476.79	349.40	307.73							653.37	442.90	390.[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTACES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7272

406

OPERATION
ITEM NO. 14
PN 1137021

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

/11-21-69

NAME NUT, BEARING RETAINING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	.6	.5	6.96	20.88	4.18	3.48	54.29	10.87	9.05	10.71	2.14	1.79	85.88	17.17	14.32
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	11.25	7.50	6.75	—	—	—						
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE	HRLY ~~SAL~~	4.0	3.1	2.8	11.95	47.80	37.12	33.30	—	—	—	6.81	5.29	4.75	54.61	42.41	38.08
7. ~~WELDING~~ BENCH INSPECTION	~~HRLY~~ ~~SAL~~	.5 1.0	.4 .8	.3 .7	9.15 11.30	4.57 11.30	3.55 8.77	3.18 7.87	—	—	—	2.26	1.76	1.57	18.13	14.08	12.62
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	1.00	.75	.75	—	—	—	.14	.10	.10	1.14	.85	.85
15:	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						109.68	70.92	62.99							212.74	111.43	97.36

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

OPERATION
ITEM NO. 15
PN 1137001

[redacted] / 12-5-69

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS VENDOR: FLUOROCARBON CO. (ROM QUOTE 12-4-69 / 2-4 WEEKS DEL.)

NAME SEAL, LABYRINTH-LOWER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL	UNIT 2	QUAN 12	TITY 44		COST 182.70	EACH 101.25	84.90									
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	30	.5	.3	6.96	20.88	3.48	2.09	54.29	9.05	7.80	10.71	1.79	1.41	85.88	14.32	11.30
3. TOOLING	HRLY SAL																
4. RAWSTOCK KEL-F AMS-3650	HRLY SAL					(VENDOR	FURNISHED)										
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	30.5	10.1	7.8	EST. 12.00	365.40	121.50	93.39	—	—	—	52.07	17.31	13.31	417.47	138.81	106.70
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.2	.1	6.96	6.96	1.39	.70	18.10	3.61	1.81	3.57	.71	.61	28.63	5.71	4.92
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	30.00	14.00	11.00	—	—	—	4.28	2.00	1.57	34.28	16.00	12.57
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						429.60	143.85	110.66							578.60	188.14	148.77

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

408

✓11-24-69

OPERATION
ITEM NO. 16
PN 1137002

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME RETAINER, LABYRINTH-LOWER

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY																
	SAL																
2. PROCUREMENT PLANNING	~~HRLY~~																
	SAL	4.5	.9	.7	6.96	31.32	6.24	4.87	81.43	16.22	12.66	16.07	3.20	2.50	128.82	25.66	20.03
3. TOOLING	HRLY																
	SAL																
4. RAWSTOCK	HRLY	—	—	—	—	36.00	24.00	21.60	—	—	—	5.13	3.42	3.08	41.13	27.42	24.68
	SAL																
5. CASTINGS OR FORGINGS	HRLY																
	SAL																
6. MACHINING TURN COMPLETE	~~HRLY~~	10.0	7.7	6.6	11.95	119.50	92.02	78.87	—	—	—	34.06	26.23	22.48	273.06	210.27	180.22
DRILL 24 HOLES	~~SAL~~	10.0	7.7	6.6		119.50	92.02	78.87									
7. ~~WELDING~~ BENCH	~~HRLY~~	1.0	.8	.7	9.15	9.15	7.05	6.04	—	—	—	3.72	2.86	2.46	29.82	22.96	19.69
INSPECT	~~SAL~~	1.5	1.2	1.0	11.30	16.95	13.05	11.19									
8. ASSY & FAB QE	HRLY																
	SAL																
9. CLEANING	HRLY																
	SAL																
10. Q C PLANNING	HRLY																
	SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.03
	SAL	.5	.15	.15	6.96	3.48	1.04	1.04	9.05	2.70	2.70	1.79	.53	.53	14.32	4.27	4.27
12. INSPECTION, SOURCE	~~HRLY~~																
	SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY																
	SAL																
14. SHIPPING	HRLY	—	—	—	—	12.00	10.00	8.00	—	—	—	1.71	1.43	1.14	13.71	11.43	9.14
	SAL																
15.	HRLY																
	SAL																
16.	HRLY																
	SAL																
TOTAL UNIT COST						357.30	253.43	217.10							539.52	334.66	285.2

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7272

OPERATION
ITEM NO. 17
PN 1137003

LO2 11-25-69

LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME VOLUTE, PUMP

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING PRECISION / PARAGON	~~HRLY~~ SAL	15.0 20.0	2.0 3.0	1.0 1.5	6.96	104.40 135.20	13.92 20.88	6.96 10.44	271.44 351.52	36.19 54.29	18.10 27.14	53.56 69.36	7.14 10.71	3.57 5.36	429.40 556.03	57.25 85.88	28.63 42.94
3. TOOLING PRECISION CASTING / PARAGON	HRLY SAL	-		---	---	8000.00 1900.00			---	---	---	1140.00 270.75	--- ---	- -	9140.00 2170.75	— —	— —
4. RAWSTOCK	HRLY SAL																
5. CASTINGS ~~OR FORGINGS~~ PRECISION CASTING	~~HRLY~~ ~~SAL~~	179.0	150.0	125.0	14.00	2500.00	2100.00	1750.00	—	—	—	356.25	299.25	249.38	2856.25	2399.25	1999.38
6. MACHINING TURN COMPLETE / MISC. MILLING	~~HRLY~~ ~~SAL~~	75.0 75.0	58.1 58.1	52.4 52.4	11.95	896.25 896.25	694.59 694.59	625.58 625.58	—	—	—	255.43	197.96	178.29	2047.93	1582.14	1429.45
7. ~~WELDING~~ DRILL ALL HOLES AND PORTS	~~HRLY~~ ~~SAL~~	175.0	134.80	115.5	11.95	2091.25	1610.26	1380.23	—	—	—	298.00	229.46	196.68	2389.25	1839.72	1576.91
8. ~~ASSY & FAB QE~~ BENCH INSPECTION	~~HRLY~~ ~~SAL~~	22.0 25.0	16.9 19.3	14.5 16.5	9.15 11.30	201.30 282.50	155.00 217.53	132.86 186.45	—	—	—	68.94	53.09	45.50	552.74	425.62	364.81
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE (PRECISION) (PARAGON)	~~HRLY~~ SAL	15.0 30.0	7.5 10.0	5.0 7.0	6.96	104.00 208.70	52.20 69.60	34.80 48.72	270.40 542.88	135.72 186.96	90.48 126.67	53.35 107.11	26.78 35.70	17.85 24.99	427.75 858.79	214.70 286.26	143.13 200.38
12. INSPECTION, REC (PRECISION)	HRLY SAL	.5 2.0	.5 1.5	.5 1.0	4.87 6.96	2.44 13.92	2.44 10.44	2.44 6.96	6.34 36.19	6.34 27.14	6.34 18.10	125.00 7.14	125.00 5.36	125.00 3.57	10.03 52.25	10.03 42.94	10.03 28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING PRECISION / PARAGON	~~HRLY~~ ~~SAL~~	—	—	—	—	37.00 57.00	32.00 46.00	27.00 46.00	—	—	—	13.90	11.12	10.40	107.40	87.12	[illegible]
15. INSPECTION, REC (PARAGON)	HRLY SAL	1.0 2.0	1.0 1.5	1.0 1.0	4.87 6.96	4.87 13.92	4.87 12.44	4.87 6.96	12.66 36.19	12.66 27.14	12.66 18.10	2.50 7.14	2.50 5.36	2.50 3.57	20.03 57.25	20.03 42.94	20.03 28.63
16.	HRLY SAL																
TOTAL UNIT COST						7549.10	5734.76	4885.[illegible]			TOOLING	11310.75			10370.1[illegible]	7100.[illegible]	[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

410

OPERATION
ITEM NO. 18
PN 1137004

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

✓11-25-69

NAME NUT. VOLUTE-PUMP RETAINING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	.9	.7	6.96	31.32	6.24	4.87	81.43	16.22	12.66	16.07	3.20	2.50	128.82	25.66	20.03
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	27.00	18.00	16.20	—	—	—	3.85	2.57	2.31	30.85	20.57	18.51
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE MISC MILLING	~~HRLY~~ ~~SAL~~	4.0 4.0	3.1 3.1	2.6 2.6	11.95	47.80 47.80	36.81 36.81	31.55 31.55	—	—	—	13.77	10.49	8.99	110.37	84.11	72.09
7. ~~WELDING~~ BENCH INSPECTION	~~HRLY~~ ~~SAL~~	2.0 2.0	1.6 1.6	1.4 1.4	9.15 11.30	18.30 33.90	14.09 27.53	12.08 24.05	—	—	—	7.44	5.94	4.86	59.64	47.60	38.99
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	22.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	2.00	1.50	1.00	—	—	—	.29	.21	.14	2.29	1.71	1.14
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						221.00	150.03	128.96							384.95	216.57	192.25

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

OPERATION
ITEM NO. 19
PN 1137005

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

✓ 11-26-69

NAME IMPELLER

		MAN HOURS			RATE	NET LOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING AEM CASTING LAMCO	~~HRLY~~ SAL	9.0 6.0	1.0 1.0	.7 .5	6.96	62.64 41.76	6.96 6.96	4.87 3.48	162.86 108.58	18.10 18.10	12.66 9.05	32.13 21.42	3.57 3.57	2.50 1.79	257.63 159.37	28.63 28.63	20.03 14.32
3. TOOLING (AEM CASTING)	HRLY SAL	—	—	—	—	13500.00	—	—	—	—	—	1923.75	—	—	15423.75	—	—
4. RAWSTOCK	HRLY SAL																
5. CASTINGS ~~OR FORGINGS~~ (SHELL MOULD) AEM CASTINGS	~~HRLY~~ ~~SAL~~	32.1	25.0	21.4	14.00	450.00	350.00	300.00	—	—	—	64.13	49.88	42.75	514.13	399.88	342.75
6. MACHINING TURN COMPLETE DRILL	~~HRLY~~ ~~SAL~~	4.0 4.0	3.5 3.0	2.5 2.0	12.00	48.00 48.00	42.00 36.00	30.00 24.00	—	—	—	13.68	11.12	7.70	109.68	89.12	61.70
7. ~~WELDING~~ MILL SPLINE	~~HRLY~~ ~~SAL~~	6.0	4.0	3.0	12.00	72.00	48.00	36.00	—	—	—	10.26	6.84	5.13	82.26	54.84	41.13
8. ~~ASSEMBLAGE~~ BENCH INSPECT	~~HRLY~~ ~~SAL~~	10.0 10.0	8.0 8.0	8.0 8.0	9.15 11.30	91.50 113.00	73.20 90.40	73.20 90.40	—	—	—	29.14	23.31	23.31	233.64	186.91	186.91
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	2.0 3.0	1.0 .5	1.0 .5	4.87 6.96	9.74 20.88	4.87 3.48	4.87 3.48	25.32 54.29	12.66 9.05	12.66 9.05	15.71	4.28	4.28	125.94	34.34	34.34
12. INSPECTION, SOURCE (A&M)	~~HRLY~~ SAL	15.0	7.5	5.0	6.96	104.00	52.20	34.80	270.40	135.72	90.48	53.35	26.78	17.85	427.75	214.70	143.13
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	--	—	—	—	25.00	18.00	14.00	—	—	—	3.56	2.57	2.00	28.56	20.57	16.00
15. INSPECTION, SOURCE (LAMCO)	~~HRLY~~ SAL	4.0	3.0	2.0	6.96	27.84	20.88	13.92	72.38	54.29	36.19	14.28	10.71	7.14	114.50	85.88	57.25
16.	HRLY SAL																
TOTAL UNIT COST						1114.36	752.95	660.02			TOOLING	15423.75			2052.[illegible]	[illegible]	[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES COST EA. INCLUDING TOOLING
17,476.63 (1)
2685.50 (10)
1303.31 (40)
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

411

412

✓ 11-26-69

OPERATION
ITEM NO. 20
PN 1137006

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME INDUCER		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.14	3.57	429.40	57.25	28.63
3. TOOLING	HRLY SAL	—	—	—	—	3200.00	—	—	—	—	—	456.00	—	—	3656.00	—	—
4. RAWSTOCK	HRLY SAL																
5. ~~CASTINGS OR~~ FORGINGS	HRLY SAL	—	—	—	—	800.00	650.00	575.00	—	—	—	114.00	92.63	81.94	914.00	742.63	656.94
6. MACHINING TURN FOR GEN. / TURN FOR SPLINE	~~HRLY~~ ~~SAL~~	40.0 15.0	30.8 11.6	26.4 9.9	11.95	478.00 179.25	368.06 138.02	315.48 118.31	—	—	—	93.66	72.12	66.82	750.91	578.20	495.61
7. ~~WELDING~~ FINISH TURN & CONTOUR / KEYS & TOOLING HOLE/TRIM PARTIAL	~~HRLY~~ ~~SAL~~	18.0 17.0	13.9 13.1	11.9 11.2	11.95	215.10 203.15	165.63 156.43	141.97 134.07	—	—	—	59.60	45.89	39.34	477.85	367.95	315.38
8. ~~ASSY & FAB OF~~ ROUGH GEN. / CUTTERS / VANE GENERATION/DUP.	~~HRLY~~ ~~SAL~~	75.0 11.0 90.0	57.8 8.5 69.3	49.5 7.3 59.4	9.95	746.25 109.45 895.50	574.61 84.28 689.54	492.53 72.24 591.03	—	—	—	249.55	192.15	164.70	2000.75	1540.30	1320.50
9. ~~CLEANING~~ SET UP & CUT SAMPLE TRACK / BENCH	~~HRLY~~ ~~SAL~~	70.0 60.0	53.9 46.2	46.2 39.6	9.50 9.15	665.00 549.00	512.05 422.73	438.90 362.34	—	—	—	173.00	133.21	114.18	1387.00	1062.99	915.42
10. ~~QC PLANNING~~ VENDOR INSPECTION	~~HRLY~~ ~~SAL~~	23.0	17.7	15.2	11.30	259.90	200.12	171.53	—	—	—	37.04	28.52	24.44	296.94	228.64	195.97
11. INSPECTION, SOURCE	~~HRLY~~ SAL	25.0	8.0	6.0	6.96	174.00	55.68	41.76	452.40	144.77	108.58	89.26	28.56	21.42	715.66	229.01	171.76
12. INSPECTION, REC	HRLY SAL	2.0 3.0	1.0 .5	1.0 .5	4.87 6.96	9.74 20.88	4.87 3.48	4.87 3.48	25.32 54.29	12.66 9.05	12.66 9.05	15.71	4.28	4.28	125.34	34.34	34.34
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	40.00	32.00	30.00	—	—	—	5.70	4.28	4.28	45.70	34.28	34.28
15. OUTSIDE PRODUCTION: THREAD GRIND & SPLINE	~~HRLY~~ ~~SAL~~	—	—	—	—	125.00 100.00	96.68 78.94	82.67 70.14	—	—	—	32.06	25.31	22.49	257.06	202.93	180.30
16.	HRLY SAL																
TOTAL UNIT COST						5674.62	4247.04	3658.28		TOOLING	3656.00				7400.61	5083.52	4349.13

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT \$12.00/HR *
INHOUSE RATE AT \$4.87/HR (HRLY) *

E W SULLIVAN X 7872

OPERATION
ITEM NO. 21
PN 1137007

L O2

LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

11-26-[illegible]

NAME NUT ASSEMBLY, IMPELLER RETAINING

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY																
	SAL																
2. PROCUREMENT PLANNING	~~HRLY~~																
	SAL	6.0	1.0	.5	6.96	41.76	6.96	3.48	108.58	18.10	9.05	21.42	3.57	1.79	159.39	28.63	14.32
3. TOOLING	HRLY																
	SAL																
4. RAWSTOCK	HRLY	—	—	—	—	33.00	22.00	19.80	—	—	—	4.70	3.14	2.82	37.70	25.14	22.62
	SAL																
5. CASTINGS OR FORGINGS	HRLY																
	SAL																
6. MACHINING TURN & THREAD	~~HRLY~~	30.0	23.4	20.8	11.95	358.50	279.63	248.98	—	—	—	57.09	39.85	35.48	409.57	319.48	284.96
	~~SAL~~																
7. ~~WELDING~~ BENCH INSPECT	~~HRLY~~	2.0	1.5	1.3	9.15	18.30	14.09	12.08	—	—	—	5.83	4.49	3.85	46.73	35.78	27.00
	~~SAL~~	2.0	1.5	1.3	11.30	22.60	17.40	14.92									
8. ASSY & FAB QE	HRLY																
	SAL																
9. CLEANING	HRLY																
	SAL																
10. Q C PLANNING	HRLY																
	SAL																
11. INSPECTION, REC	HRLY	.5	.5	.5	4.87	2.44	2.44	2.44	6.34	6.34	6.34	1.25	1.25	1.25	10.03	10.03	10.08
	SAL	.5	.15	.15	6.96	3.48	1.04	1.04	9.05	2.70	2.70	1.79	.53	.53	14.22	4.27	4.27
12. INSPECTION, SOURCE	~~HRLY~~																
	SAL	1.0	1.0	1.0	6.96	6.96	6.96	6.96	18.10	18.10	18.10	3.57	3.57	3.57	28.63	28.63	28.63
13. INSIDE LIAISON	HRLY																
	SAL																
14. SHIPPING	HRLY	—	—	—	—	4.00	2.50	2.00	—	—	—	.57	.36	.29	4.57	2.86	2.29
	SAL																
15.	HRLY																
	SAL																
16.	HRLY																
	SAL																
TOTAL UNIT COST						491.04	353.02	311.70							710.96	455.02	393.62

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

12-5-69

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS VENDOR : FLUOROCARBON CO. (ROM QUOTE 12-4-69) (2-4 WEEKS DEL.)

OPERATION
ITEM NO. 22
PN 1137008

NAME SEAL LABYRINTH - UPPER

		MAN HOURS 1	MAN HOURS 10	MAN HOURS 40	RATE PER HR	NET DOLLARS 1	NET DOLLARS 10	NET DOLLARS 40	DLO AT 260% * 1	DLO AT 260% * 10	DLO AT 260% * 40	G + A AT 14.25% * 1	G + A AT 14.25% * 10	G + A AT 14.25% * 40	TOTAL DOLLARS 1	TOTAL DOLLARS 10	TOTAL DOLLARS 40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL	UNIT 2	QUANTITY 12	44		COST 182.70	EACH 101.25	84.90									
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	.5	.3	6.96	20.88	3.48	2.09	54.29	9.05	7.80	10.71	1.79	1.41	85.88	14.32	11.30
3. TOOLING	HRLY SAL																
4. RAWSTOCK KEL-F AMS-3650	HRLY SAL					(VENDOR	FURNISHED)										
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING	HRLY SAL	30.5	10.1	7.8	EST. 12.00	365.40	121.50	93.39	—	—	—	52.07	17.31	13.31	417.47	138.81	106.70
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION SOURCE	~~HRLY~~ SAL	1.0	.2	.1	6.96	6.96	1.37	.70	18.10	3.61	1.81	3.57	.71	.61	28.63	5.71	4.92
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	30.00	14.00	11.00	—	—	—	4.28	2.00	1.57	34.28	16.00	12.57
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						429.60	143.85	110.66							590.61	189.14	149.39

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN x 7872

OPERATION
ITEM NO. 23
PN 1137009

LO2 — 12-1-69

LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME SPACER, SEAL-LABYRINTH

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	.5	.3	6.96	20.88	3.48	2.09	54.29	9.05	7.30	10.71	1.79	1.41	85.88	14.32	11.30
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	12.00	8.00	7.20	—	—	—	1.71	1.14	1.03	13.71	9.14	8.23
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE DRILL 24 HOLES	~~HRLY~~ ~~SAL~~	7.0 10.0	5.4 7.7	4.6 6.6	11.95	83.65 119.50	64.41 92.02	55.21 78.87	—	—	—	28.95	22.29	19.11	203.15	178.72	153.19
7. ~~WELDING~~ BENCH INSPECT	~~HRLY~~ ~~SAL~~	1.0 1.0	.8 .8	.7 .7	9.15 11.30	9.15 11.30	7.05 8.70	6.09 7.46	—	—	—	2.91	2.24	1.92	23.36	17.99	15.42
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	4.00	3.00	2.50	—	—	—	.57	.43	.36	4.57	3.43	2.86
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						273.36	195.71	167.03							393.65	260.52	222.[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

416

OPERATION
ITEM NO. 24
PN 1137027

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

11-25-69

NAME RETAINER,LABYRINTH-UPPER		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	4.5	.9	.7	6.96	31.32	6.24	4.87	81.43	16.22	12.66	16.07	3.20	2.50	128.82	25.66	20.03
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	30.00	20.00	18.00	—	—	—	4.28	2.85	2.57	34.28	22.85	20.57
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE DRILL 24 HOLES	~~HRLY~~ ~~SAL~~	9.0 10.0	6.9 7.7	5.9 6.6	11.95	107.55 119.50	82.81 92.02	70.98 78.87	—	—	—	32.35	24.91	21.35	259.40	199.74	171.20
7. ~~WELDING~~ BENCH INSPECT	~~HRLY~~ ~~SAL~~	1.0 1.5	.8 1.2	.7 1.0	9.15 11.30	9.15 16.95	7.05 13.05	6.04 11.19	—	—	—	3.72	2.86	2.46	29.82	22.96	19.69
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	11.00	9.00	7.00	—	—	—	1.57	1.28	1.00	12.57	10.28	8.00
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						338.35	239.22	204.61							517.87	318.41	270[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

OPERATION
ITEM NO. 25
PN 1137026

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

✓12-1-69

NAME ADAPTER, PUMP INLET

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING PRECISION CASTING PARAGON	~~HRLY~~ SAL	4.5 9.0	1.0 1.0	.7 .7	6.96	31.32 62.64	6.96 6.96	4.87 4.87	81.43 162.86	18.10 18.10	12.66 12.66	16.67 33.13	3.57 3.57	2.50 2.50	129.42 257.63	28.63 28.63	20.03 20.03
3. TOOLING PRECISION CASTING PARAGON	HRLY SAL	—	—	— —		975.00 200.00	—	— —	— —	— —	— —	138.94 28.50	— —	— —	1113.94 228.50	— —	— —
4. RAWSTOCK	HRLY SAL																
5. CASTINGS ~~[illegible]~~ PRECISION CASTING	~~HRLY~~ ~~SAL~~	42.9	32.1	28.6	14.00	600.00	450.00	400.00	—	—	—	85.50	64.13	57.00	685.50	514.13	457.00
6. MACHINING TURN COMPLETE MISC MILLING	~~HRLY~~ ~~SAL~~	20.0 4.0	15.4 3.1	13.2 2.6	11.95	239.00 47.80	184.00 36.81	157.74 31.55	—	—	—	40.87	31.47	26.97	327.67	252.28	216.26
7. ~~WELDING~~ DRILL ALL HOLES	~~HRLY~~ ~~SAL~~	15.0	11.6	9.9	11.95	179.25	138.02	118.31	—	—	—	25.54	19.67	16.86	204.79	157.69	135.17
8. ~~ASSY & FAB QE~~ BENCH INSPECTION	~~HRLY~~ ~~SAL~~	3.0 4.0	2.3 3.1	2.0 2.6	9.15 11.30	27.45 45.20	21.14 34.80	18.12 29.83	—	—	—	10.35	7.97	6.83	83.00	63.91	54.78
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, SOURCE (PRECISION) (PARAGON)	~~HRLY~~ SAL	2.0 4.5	1.5 3.0	1.0 2.7	6.96	13.92 31.32	10.44 20.88	6.96 18.79	36.19 81.43	27.14 54.29	18.10 48.85	7.14 16.07	5.36 10.71	3.57 9.64	57.25 128.82	42.94 85.89	28.63 77.28
12. INSPECTION, REC (PRECISION)	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING PRECISION CASTING PARAGON	~~HRLY~~ ~~SAL~~	—	—	—	—	10.00 17.00	8.00 14.00	6.00 12.00	—	—	—	3.85	3.14	2.57	30.85	25.14	20.57
15. INSPECTION, REC (PARAGON)	HRLY SAL	1.0 1.0	1.0 .3	1.0 .3	4.87 6.96	4.87 13.92	4.87 10.44	4.87 6.96	12.66 36.19	12.66 27.14	12.66 18.10	2.50 7.14	2.50 5.36	2.50 3.57	20.03 57.25	20.03 42.94	20.03 28.63
16.	HRLY SAL																
TOTAL UNIT COST						1329.64	750.80	824.35			TOOLING	1342.44			2066.56	1276.58	[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X 7872

✓ 12-1-69

OPERATION
ITEM NO. 26
PN 1137022

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME ROTOR, TURBINE

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	15.0	2.0	1.0	6.96	104.40	13.92	6.96	271.44	36.19	18.10	53.56	7.14	3.57	429.40	57.25	28.63
3. TOOLING	HRLY SAL	—	—	—	—	1450.0[illegible]	—	—	—	—	—	206.63	—	—	1656.63	—	—
4. ~~RAWSTOCK~~ FORGING	~~HRLY~~ ~~SAL~~	—	—	—	—	1050.00	700.00	600.00	—	—	—	149.63	99.75	85.50	1199.63	799.75	685.50
5. ~~CASTINGS OR FORGINGS~~ LATHE MILL DRILL	~~HRLY~~ ~~SAL~~	65.0 35.0 12.0	50.00 27.0 9.2	42.9 23.1 7.9	11.95	776.75 418.25 143.40	597.10 322.05 110.42	515.66 276.05 94.64	—	—	—	190.72	146.86	126.30	1429.12	1177.43	1012.65
6. ~~MACHINING~~ PANTOGRAPH CUTTERS BENCH	~~HRLY~~ ~~SAL~~	200.0 12.0 75.0	154.0 9.2 57.8	132.0 7.9 49.5	9.15	1830.00 109.80 686.25	1409.10 84.55 528.41	1207.80 72.47 452.93	—	—	—	374.21	288.14	218.48	3000.26	2310.20	1751.68
7. ~~WELDING~~ VENDOR INSPECTION	~~HRLY~~ ~~SAL~~	20.0	15.4	13.2	11.30	226.00	174.02	149.16	—	—	—	32.21	24.80	21.26	258.21	198.82	170.42
8. ASSY & FAB QE	HRLY SAL																
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION SOURCE	~~HRLY~~ SAL	15.0	7.5	5.0	6.96	104.00	52.20	34.80	270.40	135.72	90.48	53.35	26.78	17.85	427.75	214.70	143.13
12. INSPECTION REC	HRLY SAL	2.0 3.0	1.0 .5	1.0 .5	4.87 6.96	9.74 20.88	4.87 3.48	4.87 3.48	25.32 54.29	12.66 9.05	12.66 9.05	15.71	4.28	4.28	125.34	34.34	34.34
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	~~HRLY~~ ~~SAL~~	—	—	—	—	60.00	45.00	40.00	—	—	—	8.55	6.41	5.70	68.55	51.41	45.70
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						5539.47	4046.12	3458.92	TOOLING	1656.63					6937.24	[illegible]43.91	37[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E. W. SULLIVAN X 7872

OPERATION
ITEM NO. 27
PN 1137023

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

✓12-1-69

NAME BOLT, ROTOR (6 EACH) (UNIT QUAN.)

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	.6	.5	6.96	20.88	4.18	3.48	54.29	10.87	7.05	10.71	2.14	1.79	85.88	17.19	14.32
3. TOOLING	HRLY SAL																
4. RAWSTOCK	HRLY SAL	—	—	—	—	18.00	12.00	10.80	—	—	—	2.57	1.71	1.54	20.57	13.71	12.34
5. CASTINGS OR FORGINGS	HRLY SAL																
6. MACHINING TURN COMPLETE (6 EA) MILL	~~HRLY~~ ~~SAL~~	10.0 2.0	7.7 1.5	6.6 1.3	11.95	119.50 23.90	92.02 17.90	78.87 15.77	—	—	—	20.43	15.73	13.49	163.83	126.15	108.13
7. ~~WELDING~~ INSPECT	~~HRLY~~ ~~SAL~~	1.0	.8	.7	11.30	11.30	8.70	7.46	—	—	—	1.61	1.24	1.06	12.91	9.94	8.52
8. ~~[illegible]~~ OUTSIDE PRODUCTION (THREAD GRIND)	~~HRLY~~ ~~SAL~~	—	—	—	—	12.00	9.49	8.48	—	—	—	1.71	1.35	1.210	13.71	10.84	9.69
9. CLEANING	HRLY SAL																
10. Q C PLANNING	HRLY SAL																
11. INSPECTION, REC	HRLY SAL	.5 .5	.5 .15	.5 .15	4.87 6.96	2.44 3.48	2.44 1.04	2.44 1.04	6.34 9.05	6.34 2.70	6.34 2.70	1.25 1.79	1.25 .53	1.25 .53	10.03 14.32	10.03 4.27	10.03 4.27
12. INSPECTION, SOURCE	~~HRLY~~ SAL	1.0	.8	.6	6.96	6.96	5.57	4.18	18.10	14.48	10.87	3.57	2.57	2.14	28.63	22.62	17.19
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING	HRLY SAL	—	—	—	—	3.00	2.00	1.65	—	—	—	.43	.29	.24	3.43	2.29	1.89
15.	HRLY SAL																
16.	HRLY SAL																
TOTAL UNIT COST						221.46	155.84	134.17							353.30	217.04	[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

LO2 12-~~30~~-69

OPERATION
ITEM NO. 28
PN 1137024

LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS PARAGON (MACH) PICCO INDUSTRIES (CASTING) (25 WEEKS DEL.)

NAME MANIFOLD, TURBINE INLET

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING PICCO PARAGON	~~HRLY~~ SAL	30.0 30.0	5.0 5.0	3.0 3.0	6.96	208.80 208.80	34.80 34.80	20.88 20.88	542.80 542.80	90.48 90.48	54.29 54.29	107.10 107.10	17.85 17.85	10.71 10.71	858.70 858.70	143.13 149.13	85.88 85.88
3. TOOLING PICCO INDUSTRIES ~~[illegible]~~ PARAGON	~~HRLY~~ ~~SAL~~	— —	— —	— —	— —	24000 1500	— —	— —	— —	— —	— —	3420 213.75	— —	 —	27420 1713.75	—	— —
4. RAWSTOCK PARAGON	~~HRLY~~ ~~SAL~~	—	—	—	—	1860.00	1240.00	1116.00	—	—	—	265.00	176.70	159.00	2125.00	1416.70	1275.00
5. CASTINGS ~~OR FORGINGS~~ PICCO INDUSTRIES	~~HRLY~~ ~~SAL~~	257.1	85.7	64.3	14.00	3600.00	1200.00	900.00	—	—	—	513.00	171.00	128.00	4113.00	1371.00	1028.00
6. MACHINING TURN COMPLETE MISC. MILLING	~~HRLY~~ ~~SAL~~	150.0 80.0	119.0 65.0	104.0 60.0	11.95	1792.50 956.0	1422.05 776.75	1242.80 717.0	—	—	—	391.66	313.33	279.27	3140.16	2512.13	2239.07
7. ~~WELDING~~ DRILL ALL HOLES & PORTS	HRLY SAL	125.0	98.0	87.5	11.95	1493.75	1172.30	1045.63	—	—	—	212.86	167.05	149.00	1706.61	1339.35	1194.63
8. ~~ASSY & PAD QC~~ BENCH	~~HRLY~~ ~~SAL~~	50.0	39.0	35.0	9.15	457.50	356.85	320.25	—	—	—	65.19	50.85	45.64	522.69	407.70	365.89
9. ~~CLEANING~~ INSPECT	~~HRLY~~ ~~SAL~~	35.0	27.0	23.0	11.30	395.50	305.10	259.90	—	—	—	56.36	43.48	37.04	451.86	303.38	296.94
10. Q C PLANNING	HRLY SAL																
11. INSPECTION SOURCE PICCO PARAGON	~~HRLY~~ SAL	30.0 40.0	10.0 15.0	8.0 10.0	6.96	208.80 278.40	69.60 104.40	55.68 69.60	542.88 723.84	180.96 271.44	144.77 180.96	107.11 142.88	35.70 53.56	28.56 35.70	858.79 1145.06	286.26 429.40	229.01 286.86
12. INSPECTION, REC. PICO	HRLY SAL	.5 2.0	.5 1.5	.5 1.0	4.87 6.96	2.44 13.92	2.44 10.44	2.44 6.96	6.34 36.19	6.34 27.14	6.34 18.10	1.25 7.14	1.25 5.36	1.25 3.57	10.03 57.25	10.03 42.94	10.03 28.63
13. INSIDE LIAISON	HRLY SAL																
14. SHIPPING PICO PARAGON	~~HRLY~~ ~~SAL~~	—	—	—	—	60.00 94.00	53.00 60.00	50.00 54.00	—	—	—	21.95	16.39	14.82	175.95	131.39	118.82
15. INSPECTION, REC. PARAGON	HRLY SAL	2.0 4.0	2.0 3.0	2.0 2.0	4.87 6.96	9.74 27.84	9.74 20.88	9.74 13.92	25.32 72.38	25.32 54.29	25.32 36.19	5.00 14.28	5.00 10.71	5.00 7.14	40.06 114.50	40.06 85.88	40.06 57.25
16.	HRLY SAL																
TOTAL UNIT COST						11,668	6,875	5,706			TOOLING	24,133.75			16,178	8,662	7,941

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT $12.00/HR *
INHOUSE RATE AT $4.87/HR (HRLY) *

E W SULLIVAN X7872

✓12-2-69

OPERATION
ITEM NO. (*) ASSEMBLY TURBOPUMP
PN 1137000

LO2
LOW COST TURBOPUMP STUDY
UNIT COST (BASE CASE)
COST ANALYSIS

NAME LO2 TURBOPUMP ASSEMBLY

		MAN HOURS			RATE	NET DOLLARS			DLO AT 260% *			G + A AT 14.25% *			TOTAL DOLLARS		
		1	10	40	PER HR	1	10	40	1	10	40	1	10	40	1	10	40
1. ADVANCE QUOTES/CONSULTING	HRLY SAL																
2. PROCUREMENT PLANNING	~~HRLY~~ SAL	3.0	1.0	1.0	6.96	20.88	6.96	6.96	54.29	18.10	18.10	10.71	3.57	3.57	85.88	28.63	28.63
3. TOOLING, OP ROTOR LOCKS (2 30) LEAK CHECK KIT (4 PLATES)	~~HRLY~~ ~~SAL~~				400.00 4110.00												
4. ~~RAWSTOCK~~ SHAFT POSITIONING FIXTURE SPANNER WRENCHES (3)	~~HRLY~~ ~~SAL~~				300.00 600.00							3135.50			25135.50		
5. ~~CASTINGS OR FORGINGS~~ BUILD UP STAND	~~HRLY~~ ~~SAL~~				500.00												
6. MACHINING	HRLY SAL																
7. WELDING	HRLY SAL																
8. ASSY & FAB QE	~~HRLY~~ SAL	20.0	20.0	20.0	6.96	139.20	139.20	139.20	361.92	361.92	361.92	71.41	71.41	71.41	572.53	572.53	572.53
9. CLEANING	HRLY SAL	13.0 2.5	7.0 1.5	5.0 1.0	4.87 6.96	63.31 17.40	34.09 10.44	24.35 6.96	164.61 45.24	88.63 27.14	63.31 18.10	41.40	22.84	16.06	331.96	183.14	128.78
10. ~~Q C PLANNING~~ (LOG BOOK) Q A DOCUMENT CONTROL	~~HRLY~~ SAL	27.0	20.0	13.0	6.96	187.92	139.20	70.48	488.59	361.92	235.25	96.40	71.41	46.42	772.91	572.53	372.15
11. INSPECTION	HRLY SAL		27.6	22			139	107		361	278						
12. INSPECTION, ASSY	HRLY SAL	42.0 11.2	26.0 6.4	20.0 5.2	4.87 6.96	204.54 77.95	126.62 44.54	97.40 36.19	531.80 202.67	329.21 115.80	253.24 94.09	144.92	87.80 96.33	67.53 75.33	1161.88	704.50 772.33	549.[illegible] 604.[illegible]
13. INSIDE LIAISON	~~HRLY~~ SAL	55.0	7.0 34.0	5.7 26.5	6.96	382.80	236.64	184.44	995.28	615.26	479.54	196.38	121.40	94.62	1574.46	973.30	758.60
14. ~~SHIPPING~~ PRODUCTION CONTROL	~~HRLY~~ SAL	12.0	12.0	12.0	6.96	83.52	83.52	83.52	217.15	217.15	217.15	42.85	42.85	42.85	343.52	343.52	343.52
15. ASSEMBLY LABOR	HRLY SAL	140.0 42.0	27 80.0 26.0	72 65.0 20.0	4.87 6.96	681.80 292.32	429 389.60 180.96	348 316.55 139.20	1772.68 760.03	1115 1012.90 470.50	905 823.03 361.92	499.72	292.70 322.05	233.80 257.07	4006.55	2346.72 2582.05	1874.5[illegible] 2061.87
16. SHOP PLANNING (MFG ENG)	~~HRLY~~ SAL	35.0	3.5	2.0	6.96	243.60	24.36	13.92	633.36	63.34	36.19	124.97	12.50	7.14	1001.93	100.20	57.25
TOTAL UNIT COST						2395.24	1416.13	1139.17		ASSY	TOOLING	2513.50			9851.62	5825.07	4685.[illegible]

ALT → 6128.23 49[illegible]

* MIDPOINT OF EFFORT - JAN '71

NET OP DOLLARS x PERCENTAGES
ABOVE = NET DOLLARS (INHOUSE)

OP RATE AT \$12.00/HR *
INHOUSE RATE AT \$4.87/HR (HRLY) * +50% +50%

E W SULLIVAN X 7872

APPENDIX J

OXIDIZER AND FUEL TURBOPUMP WEIGHT ANALYSES

WEIGHT ANALYSIS

LOW COST TURBOPUMP (OXID)

P/N 1137000 (NPSH = 25 FT)

Item No.	Part Name	Material	Density	Area	Diameter	Weight	Part No.	Qty
1	Housing, Bearing	347	.290	9.90	5.74	52.0	1137010	1
2	Shaft	Inco-X	.296	10.36	1.8	17.3	1137011	1
3 & 13	Bearing, Ball-Upper & Lower	440 C	.280	.88	3.4	5.4	1137012	2
4	Seal Assy, Bellows-Upper	SS	.290	1.28	4.38	5.1	1137013	1
5	Seal Ring, Running-Upper	347	.290	.24	2.8	.6	1137014	1
6	Seal Ring, Running-Lower	347	.290	1.24	3.54	4.0	1137015	1
7	Seal Assy, Shaft Riding	SS	.290	.94	5.60	4.8	1137016	1
8	Seal Assy, Bellows-Lower	SS	.290	.96	5.00	4.4	1137017	1
9	Nut, Seal Retaining	Inco-X	.296	.26	6.4	1.6	1137018	1
10	Filter, SS (10 Micron)	SS	.290	.3	5.2	1.5	1137019	1
12	Spacer, Bearing	Inco-X	.296	1.7	2.6	4.1	1137020	1
14	Nut, Bearing Retaining	A-286	.286	.22	2.82	.6	1137021	1
15	Seal, Labyrinth-Lower	Kel-F	.79	.52	10.3	1.4	1137001	1
16	Retainer, Labyrinth-Lower	Alum	.10	.80	6.0	1.5	1137002	1
17	Volute, Pump	Alum	.10	32.56	14.3	146.0	1137003	1
17	Strut Area	Alum	.10	Est.	Est.	4.0	1137003	1
18	Nut, Volute-Pump Ret.	Inco-X	.296	.30	5.4	1.5	1137004	1
19	Impeller	Alum	.100	6.00	6.24	11.7	1137005	1
19	Blade Area x .20%	Alum	.100	5.92	8.65	3.2	1137005	1
20	Inducer	Alum	.100	1.91	2.27	1.4	1137006	1
20	Blade Area x .20%	Alum	.100	8.66	5.35	2.9	1137006	1
21	Nut Assy, Impeller Ret.	K-Monel	.290	2.50	.62	1.4	1137007	1
22	Seal, Labyrinth-Upper	Kel-F	.79	.36	9.6	.9	1137008	1
23	Spacer, Seal Labyrinth	Alum	.100	.60	10.0	1.9	1137009	1
24	Retainer, Labyrinth-Upper	Alum	.100	1.00	10.8	3.4	1137027	1
25	Adapter, Pump Inlet	Alum	.100	8.12	10.92	28.0	1137026	1
26	Rotor, Turbine	718	.296	5.32	5.96	29.4	1137022	1
26	Blade Area	718	.296	Est.	Est.	3.0	1137022	1
28	Manifold, Turbine Inlet	718	.296	8.52	18.60	147.0	1137024	1
28	Manifold, Flange	718	.296	Est.	Est.	15.5	1137024	1
28	Manifold, Blade Area	718	.296	Est.	Est.	5.0	1137024	1
				TOTAL WEIGHT		511.5#		

WEIGHT ANALYSIS

LOW COST TURBOPUMP (OXID)

P/N 1137050 (NPSH = 25 FT)

Item No.	Part Name	Material	Density	Area	Diameter	Weight	Part No.	Qty
1	Housing, Bearing	347	.290	9.62	5.08	44.5		1
2	Shaft	Inco-X	.296	10.24	1.45	13.8		1
3 & 13	Bearing, Ball-Upper & Lower	440 C	.280	.56	2.72	2.7		2
4	Seal Assy, Bellows-Upper	SS	.290	Est.	Est.	4.5		1
5	Seal Ring, Running-Upper	347	.290	Est.	Est.	.5		1
6	Seal Ring, Running-Lower	347	.290	Est.	Est.	3.5		1
7	Seal Assy, Shaft Riding	SS	.290	Est.	Est.	4.0		1
8	Seal Assy, Bellows-Lower	SS	.290	Est.	Est.	3.9		1
9	Nut, Seal Retaining	Inco-X	.296	Est.	Est.	1.3		1
10	Filter, SS (10 Micron)	SS	.290	Est.	Est.	1.1		1
12	Spacer, Bearing	Inco-X	.296	Est.	Est.	3.5		1
14	Nut, Bearing Retaining	A-286	.286	Est.	Est.	.5		1
15	Seal, Labyrinth-Lower	Kel-F	.97	Est.	Est.	1.1		1
16	Retainer, Labyrinth-Lower	Alum.	.10	Est.	Est.	1.1		1
17	Volute, Pump	Alum.	.10	31.44	12.52	123.6		1
17	Volute, Strut Area	Alum.	.10	Est.	Est.	4.0		1
18	Nut, Volute-Pump Ret.	Inco-X	.296	Est.	Est.	1.3		1
19	Impeller	Alum.	.100	5.66	5.66	10.1		1
19	Blade Area x .20%	Alum.	.100	4.68	7.42	2.2		1
20	Inducer	Alum.	.100	2.06	1.82	1.2		1
20	Blade Area x .20%	Alum.	.100	9.06	4.98	2.8		1
21	Nut Assy, Impeller Ret.	K-Monel	.290	Est.	Est.	1.1		1
22	Seal, Labyrinth-Upper	Kel-F	.79	Est.	Est.	..7		1
23	Spacer, Seal Labyrinth	Alum.	.100	Est.	Est.	1.3		1
24	Retainer, Labyrinth-Upper	Alum.	.100	Est.	Est.	3.0		1
25	Adapter, Pump Inlet	Alum.	.100	6.4	9.7	19.5		1
26	Rotor, Turbine	718	.296	4.84	4.82	21.7		1
26	Blade Area	718	.296	Est.	Est.	2.8		1
28	Manifold, Turbine Inlet	718	.296	8.44	18.16	142.5		1
28	Flange	718	.296	1.94	9.52	17.2		1
28	Blade Area	718	.296	Est.	Est.	4.5		1
				TOTAL WEIGHT		445.5#		

WEIGHT ANALYSIS

LOW COST TURBOPUMP (OXID)

P/N 1137040 (NPSH = 15 FT)

Item No.	Part Name	Material	Density	Area	Diameter	Weight	Part No.	Qty
1	Housing, Bearing	347	.290	10.18	7.80	7.2		1
2	Shaft	Inco-X	.296	10.92	2.84	28.8		1
3 & 13	Bearing, Ball-Upper & Lower	440 C	.280	1.32	5.02	11.6		2
4	Seal Assy, Bellows-Upper	SS	.290	1.58	5.96	8.6		1
5	Seal Ring, Running-Upper	347	.290	.24	4.32	1.0		1
6	Seal Ring, Running-Lower	347	.290	1.46	5.30	7.1		1
7	Seal Assy, Shaft Riding	SS	.290	1.08	7.48	8.3		1
8	Seal Assy, Bellows-Lower	SS	.290	1.20	7.07	7.7		1
9	Nut, Seal Retaining	Inco-X	.296	.26	7.68	1.9		1
10	Filter SS (10 Micron)	SS	.290	.34	7.52	2.3		1
12	Spacer, Bearing	Inco-X	.296	1.6	3.8	5.7		1
14	Nut, Bearing Retaining	A-286	.286	Est.	Est.	.8		1
15	Seal, Labyrinth-Lower	Kel-F	.79	Est.	Est.	2.0		1
16	Retainer, Labyrinth-Lower	Alum	.10	Est.	Est.	2.1		1
17	Volute, Pump	Alum	.10	36.8	18.66	215.6		1
17	Volute, Strut Area	Alum	.10	Est.	Est.	8.0		1
18	Nut, Volute-Pump Ret.	Inco-X	.296	Est.	Est.	2.1		1
19	Impeller	Alum	.100	8.24	8.70	22.5		1
19	Blade Area x .20%	Alum	.100	8.16	11.68	6.0		1
20	Inducer	Alum	.100	2.00	3.2	2.1		1
20	Blade Area x .20%	Alum	.100	9.44	6.66	3.9		1
21	Nut Assy, Impeller Ret.	K-Monel	.290	Est.	Est.	1.9		1
22	Seal Labyrinth-Upper	Kel-F	.79	Est.	Est.	1.3		1
23	Spacer, Seal Labyrinth	Alum	.100	Est.	Est.	2.5		1
24	Retainer, Labyrinth-Upper	Alum	.100	Est.	Est.	6.0		1
25	Adapter, Pump Inlet	Alum	.100	14.48	14.36	64.8		1
26	Rotor, Turbine	718	.296	11.48	8.92	95.2		1
26	Blade Area	718	.296	Est.	Est.	4.0		1
28	Manifold, Turbine Inlet	718	.296	9.68	26.72	240.4		1
28	Manifold Flange	718	.296	Est.	Est.	14.0		1
28	Manifold Blade Area	718	.296	1.92	12.00	7.0		1
				TOTAL WEIGHT		792.4#		

WEIGHT ANALYSIS

LOW COST TURBOPUMP (OXID)

P/N 1137040 (NPSH = 130 FT

Item No.	Part Name	Material	Density	Area	Diameter	Weight	Part No.	Qty
1	Housing, Bearing/Backplate	347	.290	19.92	11.50	209.0	1136912	1
1	Ribs (6" thick)	347	.290	16.92	-	35.4	1136912	12
2	Shaft	Inco-X	.296	5.08	2.10	9.9	1136913	1
5	Spacer, Bearing	Inco-X	.296	.86	2.60	2.1	1136915	1
3.5 & 6.5	Spacer, Bearing-Upper & Lower	Inco-X	.296	.06	2.50	.3	1136926	2
8	Coupling, Turbine	Inco-X	.269	2.92	2.30	6.3	1136916	1
9	Bolt, Shaft-Coupling	Inco-X	.296	2.30	.40	.9	1136917	1
10	Nut, Coupling	A-286	.286	.24	1.00	.2	1136918	1
11	Labyrinth, Shaft	Phos. Bronze	.320	.20	5.00	1.1	1136919	1
12	Carrier, Bearing-Upper	Inco-X	.296	.50	4.0	1.9	1136920	1
13	Carrier, Bearing-Lower	Inco-X	.296	.39	3.86	1.4	1136921	1
14	Spacer, Shim-Brg. Ret.	Inco-X	.296	.04	4.70	.2	1136922	1
15	Spacer, Bearing Ret.	Inco-X	.296	.10	4.70	.4	1136923	1
16	Labyrinth, Coupling	Phos. Bronze	.320	.40	4.00	1.6	1136924	1
17	Seal Assy, Turbine Coupling	347	.280	1.28	6.00	6.7	1136925	1
18	Rotor, Turbine #1	718	.296	4.80	3.86	16.6	1136930	1
18	Blade Area	718	.296	Est.	Est.	1.5	1136930	1
19	Rotor, Turbine #2	718	.296	4.64	3.86	16.5	1136931	1
19	Blade Area	718	.296	Est.	Est.	1.5	1136931	1
21	Vane, Stator	718	.296	1.08	11.26	11.7	1136933	1
21	Blade Area	718	.296	Est.	Est.	1.5	1136933	1
22	Ring, Orifice, Low Pressure	718	.296	.16	6.3	.9	1136901	1
23	Nut, Ring Orifice - L.P.	347	.290	.08	6.8	.5	1136902	1
27	Ring, Orifice-High Pressure	718	.296	.06	15.4	.9	1136904	1
28	Nut, Ring Orifice - H.P.	347	.290	.21	15.7	3.0	1136905	1
29	Vane, Diffuser-Pump	347	.290	1.14	16.4	17.0	1136906	1
29	Blade Area	347	.290	Est.	Est.	2.0	1136906	1
30	Impeller, Pump	Titanium	.160	11.62	5.54	32.3	1136907	1
30	Blade Area x 20%	Titanium	.160	5.36	9.15	4.9	1136907	1
31	Inducer, Pump	Titanium	.160	2,86	3.16	4.5	1136908	1
31	Blade Area x 20%	Titanium	.160	5.34	5.95	3.2	1136908	1
32	Nut Assy, Impeller Ret.	Alum.	.100	.60	2.20	.4	1136909	1
33	Manifold Assy, Turbine Inlet	718	.296	8.36	13.50	110.4	1136934	1
33	Blade Area	718	.296	Est.	Est.	2.0	1136934	1
34	Velute, Pump Housing	347	.290	25.88	16.47	388.0	1136910	1
34	Strut Area	347	.290	Est.	Est.	2.0	1136910	
3,4,6,7	Bearing, Ball (4 ea)	440 C	.280	.42	3.0	4.4	1136914	4
				TOTAL WEIGHT		903.1#		

WEIGHT ANALYSIS

LOW COST TURBOPUMP (FUEL)

P/N 1136950 (NPSH - 75 FT)

Item No.	Part Name	Material	Density	Area	Diameter	Weight	Part No.	Qty
1	Housing, Bearing/Back Plate	347	.290	26.92	14.96	366.7		1
1	Ribs (.6" Thick)	347	.290	29.90		62.4		12
2	Shaft	Inco-X	.296	7.80	3.12	22.6		1
5	Spacer, Bearing	Inco-X	.296	1.12	3.34	3.8		1
3.5 & 6.5	Spacer, Brg-Upper-Lower	Inco-X	.296	Est.	Est.	.6		2
8	Coupling, Turbine	Inco-X	.296	3.26	4.12	12.5		1
9	Bolt, Shaft Coupling	Inco-X	.296	3.48	1.26	4.1		1
10	Nut, Coupling	A-286	.286	.27	2.22	.5		1
11	Labyrinth, Shaft	Phds. Bronze	.320	.28	7.72	2.2		1
12	Carrier, Brg-Upper	Inco-X	.296	.84	6.58	4.5		1
13	Carrier, Brg-Lower	Inco-X	.296	.84	6.58	4.5		1
14	Spacer, Shim-Brg. Ret.	Inco-X	.296	Est.	Est.	.3		1
15	Spacer, Brg. Ret.	Inco-X	.296	Est.	Est.	.8		1
16	Labyrinth, Coupling	Phds. Bronze	.320	.70	5.24	3.7		1
17	Seal Assy, Turbine Coupling	.347	.280	.94	6.64	5.5		1
18	Rotor, Turbine #1	718	.296	7.4	6.18	42.5		1
18	Blade Area	718	.296	7.4	6.18	4.00		1
19	Rotor, Turbine #2	718	.296	7.4	6.18	42.5		1
19	Blade Area	718	.296	7.4	6.18	4.0		1
21	Vane, Stator	718	.296	1.16	15.44	16.7		1
21	Blade Area	718	.296	1.16	15.44	3.0		1
22	Ring, Orifice-Low Pressure	718	.296	Est.	Est.	1.3		1
23	Nut, Ring Orifice-L.P.	347	.290	Est.	Est.	.8		1
27	Ring, Orifice-High Pressure	718	.296	Est.	Est.	1.3		1
28	Nut, Ring Orifice-H.P.	347	.290	.16	24.0	3.5		1
29	Vane, Diffuser-Pump	347	.290	1.24	20.2	22.8		1
29	Blade Area	347	.290	1.24	20.2	3.0		1
30	Impeller, Pump	Titanium	.160	14.92	7.30	54.7		1
30	Blade Area x .20%	Titanium	.160	8.32	12.08	10.1		1
31	Inducer, Pump	Titanium	.160	3.16	3.64	5.8		1
31	Blade Area x .20%	Titanium	.160	6.16	6.96	4.3		1
32	Nut Assy, Impeller Ret.	Alum	.100	.66	2.90	.6		1
33	Manifold Assy, Turbine Inlet	718	.296	11.08	19.32	175.4		1
33	Blade Area	718	.296	.72	.12	.8		1
34	Volute, Pump Housing	347	.290	28.20	21.62	555.2		1
34	Strut Area	347	.290	Est.	Est.	3.0		1
3,4,6,7	Bearing Ball (4 ea)	440 C	.280	1.34	5.08	24.0		4

WEIGHT ANALYSIS

LOW COST TURBOPUMP (FUEL)

P/N 1136960 (NPSH - 160 FT)

Item No.	Part Name	Material	Density	Area	Diameter	Weight	Part No.	Qty
1	Housing, Bearing/Back Plate	347	.290	17.04	12.76	198.0		1
1	Ribs (.6" Thick)	347	.290	14.28	-	29.8		12
2	Shaft	Inco-X	.296	3.78	1.51	5.3		1
5	Spacer, Bearing	Inco-X	.296	1.09	2.36	2.4		1
3.5 & 6.5	Spacer, Brg-Upper-Lower	Inco-X	.296	Est.	Est.	.2		2
8	Coupling, Turbine	Inco-X	.296	2.68	2.13	5.3		1
9	Bolt, Shaft-Coupling	Inco-X	.296	1.56	.35	.6		1
10	Nut, Coupling	A-286	.286	Est.	Est.	.2		1
11	Labyrinth, Shaft	Phos Bronze	.320	.44	3.73	1.6		1
12	Carrier, Bearing-Upper	Inco-X	.296	.41	3.80	1.5		1
13	Carrier, Bearing-Lower	Inco-X	.296	.41	3.80	1.5		1
14	Spacer, Shim-Brg. Ret.	Inco-X	.296	Est.	Est.	.1		1
15	Spacer, Bearing Ret.	Inco-X	.296	Est.	Est.	.3		1
16	Labyrinth, Coupling	Phos. Bronze	.320	.26	5.24	1.4		1
17	Seal Assy, Turbine Coupling	347	.280	.78	5.64	3.9		1
18	Rotor, Turbine #1	718	.296	4.38	3.52	14.3		1
18	Blade Area	718	.296	Est.	Est.	1.3		1
19	Rotor, Turbine #2	718	.296	4.38	3.52	14.3		1
19	Blade Area	718	.296	Est.	Est.	1.3		1
21	Vane, Stator	718	.296	.94	10.74	9.4		1
21	Blade Area	718	.296	Est.	Est.	.9		1
22	Ring, Orifice-Low Pressure	718	.296	Est.	Est.	.8		1
23	Nut, Ring Orifice - L.P.	347	.290	Est.	Est.	.4		1
27	Ring, Orifice-High Pressure	718	.296	Est.	Est.	.6		1
28	Nut, Ring Orifice-H.P.	347	.290	.16	14.0	2.0		1
29	Vane, Diffuser-Pump	347	.290	1.24	14.7	16.6		1
29	Blade Area	347	.290	Est.	Est.	1.7		1
30	Impeller, Pump	Titanium	.160	11.08	4.86	27.1		1
30	Blade Area x 20%	Titanium	.160	4.60	8.55	3.9		1
31	Inducer, Pump	Titanium	.160	2.92	2.74	4.3		1
31	Blade Area x 20%	Titanium	.160	5.36	5.79	3.1		1
32	Nut Assy, Impeller Ret.	Alum.	.100	.58	1.90	.3		1
33	Manifold Assy, Turbine Inlet	718	.296	9.77	12.50	102.0		1
33	Blade Area	718	.296	Est.	Est.	1.5		1
34	Volute, Pump Housing	347	.290	24.04	15.43	337.8		1
34	Strut Area	347	.290	Est.	Est.	1.5		1
3,4,6,7	Bearing, Ball (4 ea)	440 C	.280	.53	2.17	4.0		4
				TOTAL WEIGHT		800.3#		

APPENDIX K

DESIGN REQUIREMENTS, TURBOPUMP FUNCTIONAL ALTERNATIVES

DESIGN REQUIREMENTS
TURBOPUMP FUNCTIONAL ALTERNATIVES

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Bearing Housing/Backplate, Fuel (1)			
Size (OD)	25.0 in.	25.0 in.	25.0 in.
Material	Cast 347	Cast 347	Cast 347
Surface Finish	63	125	250
Tolerance			
Pilot Diameters	$\pm$0.001	$\pm$0.003	$\pm$0.005
Bearing Diameters	$\pm$0.0005	$\pm$0.0005	$\pm$0.0005
Axial Dimensions	$\pm$0.001	$\pm$0.003	$\pm$0.005
Quality Control	Current Aerospace*	Current Aerospace	Minimum**
Shaft, Fuel (2)			
Size (Bearing Diameter)	2.25 in.		
Material	Inconel X		
Tolerance			
Diameters	$\pm$0.0005	No Change	No Change
Axial Dimensions	$\pm$0.001		
Surface Finish	16/63		
Quality Control	Current Aerospace		
Dynamic Balance	Required		

* 100% Dimensional, Material Certification and Traceability

** Critical Dimensions only, Material Certification and Traceability

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Bearings, Fuel (3) (4) (6) (7)			
Size	60 mm		
Number/Type	4/Preloaded Ball		
Material	440C/Armalon	No Change	No Change
Class	5		
Quality Control	Current Aerospace		
Spacer, Bearing-Upper and Lower (3.5) (6.5)			
Size (OD)	2.750		
Material	Inconel X		
Tolerance			
Diameter	± 0.0005	No Change	No Change
Surface Finished	16/63		
Quality Control	Current Aerospace		
Turbine Shaft Coupling, Fuel (8)			
Size (OD)	5.5 in.		
Material	Inconel X		
Surface Finish	16/63		
Tolerance			
Diameters	± 0.0005	No Change	No Change
Axial Dimensions	± 0.001		
Quality Control	Current Aerospace		
Dynamic Balance	Required		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Bolt, Shaft Coupling (9)			
Size (Thread Diameter)	1.125 in.		
Material	Inconel X		
Tolerance			
Diameter	±0.0005		
	± 0.010		
Thread	Class A	No Change	No Change
Concentricity	0.001		
Surface Finish	32/63		
Quality Control	Current Aerospace		
Nut, Coupling (10)			
Size (OD)	1.5 in.		
Material	A 286		
Tolerance			
Thread	0.625 Class A	No Change	No Change
Squareness	0.001		
Surface Finish	63		
Quality Control	Current Aerospace		
Labyrinth, Shaft (11)			
Size (OD)	4.5 in.		
Material	Phosphor Bronze		
Tolerance			
Diameter	±0.001/-0.000	No Change	No Change

Subcomponent/Requirement	Base Value	Alernative No. 1	Alternative No. 2
Squareness	0.001		
Surface Finish	32/63		
Quality Control	Current Aerospace		
Carrier, Bearing - Upper (12)			
Size (OD)	4.25 in.		
Material	Inconel X		
Tolerance			
Diameter	+0.0000		
	-0.0005	No Change	No Change
Concentricity	0.001		
Surface Finish	16/63		
Quality Control	Current Aerospace		
Carrier, Bearing - Lower (13)			
Size (OD)	4.25 in.		
Material	Inconel X		
Tolerance			
Diameter	+0.0000		
	-0.0005	No Change	No Change
Concentricity	0.001		
Surface Finish	16/63		
Quality Control	Current Aerospace		
Spacer, Shim-Bearing Retaining (14)			
Size (OD)	5.0 in.		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Material	Inconel X		
Tolerance			
Diameter	0.001		
Parallelism	0.001	No Change	No Change
Surface Finish	63		
Quality Control	Current Aerospace		
Spacer, Bearing Retaining (15)			
Size (OD)	5.0 in.		
Material	Inconel X		
Tolerance			
Diameter	0.001	No Change	No Change
Parallelism	0.001 (or less)		
Surface Finish	63		
Quality Control	Current Aerospace		
Labyrinth, Coupling (16)			
Size (OD)	5.0 in.		
Material	Phosphor Bronze		
Tolerance			
Diameter	± 0.0005	No Change	No Change
Flatness	0.0005		
Surface Finish	63		
Quality Control	Current Aerospace		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Turbine Seal, Fuel (17)			
Type	Shaft Riding		
Size (ID)	2.5 in.		
Tolerance			
Flange Dimensions	±0.010	No Change	No Change
Sealing Elements	±0.0005		
Quality Control			
1st Stage Turbine Rotor, Fuel (18)			
Size (OD)	10.8 in.	10.8 in.	10.8 in.
Material	Forged 718	Forged 718	Forged 718
Surface Finish	63	125	250
Tolerance			
Blade	±0.003	±0.010	±0.010
Diameters and Axial Dim's	±0.001	±0.005	±0.010
Quality Control	Current Aerospace	Current Aerospace	Minimum
Dynamic Balance	Required	Required	Required
2nd Stage Turbine Rotor, Fuel (19)			
Size (OD)	10.8 in.	10.8 in.	10.8 in.
Material	Forged 718	Forged 718	Forged 718
Surface Finish	63	250	250
Tolerance			
Blade	±0.003	±0.010	±0.010
Diameters	±0.001	±0.010	±0.010

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Quality Control	Current Aerospace	Current Aerospace	Minimum
Dynamic Balance	Required	Required	Required
Bolt, Turbine Rotor (20)		No Change	No Change
Size (shank)	0.375		
Material	718		
Tolerance			
Diameters	± 0.0005		
Tir	0.001		
Surface Finish	32		
Quality Control	Current Aerospace		
Stator Vane, Fuel Turbine (21)			
Size (OD)	12.6 in.	12.6 in.	12.6 in.
Material	Forged 718	Cast and Machined 718	Cast 718
Tolerance			
Vane Profile	± 0.003	± 0.005	± 0.010
Diameters	± 0.003	± 0.003	± 0.010
Surface Finish	63	125	250
Quality Control	Current Aerospace	Current Aerospace	Minimum
Low Pressure Orifice, Fuel (22)			
Size (OD)	7.0 in.		
Material	718		
Tolerance		No Change	No Change
Diameters	± 0.003		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Flatness	±0.001		
Surface Finish	32		
Quality Control	Current Aerospace		
Nut, Ring Orifice - Low Pressure (23)			
Size (OD)	6.75 in.	No Change	No Change
Material	347		
Tolerance			
Diameters	±0.0005		
Squareness	0.001		
Surface Finish	63		
Quality Control	Current Aerospace		
Ring, Orifice-High Pressure (27)			
Size (OD)	16.0 in.	No Change	No Change
Material	Inconel 718		
Tolerance			
Diameters	±0.003		
Flatness	±0.001		
Surface Finish	32		
Quality Control	Current Aerospace		
Nut, Ring Orifice-High Pressure (28)			
Size (OD)	16.0 in.	No Change	No Change
Material	347		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Tolerance			
Diameter (OD)	Class A Thread		
(ID)	0.001		
Squareness	0.001		
Surface Finish	63		
Quality Control	Current Aerospace		
Pump Diffuser, Fuel (29)			
Size (Base Circle Diameter)	15.5 in.	15.5 in.	15.5 in.
Material	347	Cast Aluminum (machined)	Cast Aluminum
Surface Finish	63	125	250
Vane Tolerance	±0.003	±0.003	±0.010
Diameter Tolerance	±0.003	±0.003	±0.010
Quality Control	Current Aerospace	Current Aerospace	Minimum
Impeller, Fuel (30)			
Size (OD)	14.6 in.	14.6 in.	14.6 in.
Material	Forged Titanium	Forged Titanium	Forged Titanium
Surface Finish	63	125	250
Vane Tolerance	±0.003	±0.005	±0.010
Diameter Tolerance	±0.003	±0.005	±0.010
Quality Control	Current Aerospace	Current Aerospace	Minimum
Dynamic Balance	Required	Required	Required
Inducer, Fuel (31)			
Size (OD)	8.4 in.	8.4 in.	8.4 in.

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Material	Forged Titanium	Forged Titanium	Forged Titanium
Surface Finish	63	125	250
Vane Tolerance	±0.003	±0.005	±0.010
Diameter Tolerance	±0.003	±0.005	±0.010
Quality Control	Current Aerospace	Current Aerospace	Minimum
Dynamic Balance	Required	Required	Required
Nut Assembly, Impeller Retaining (32)			
Size (OD)	3.1 in.	No Change	No Change
Material	Aluminum		
Tolerance			
Diameter (Thread)	Class A		
(ID)	±0.001		
Contour Thickness	±0.002		
Surface Finish	63		
Quality Control	Current Aerospace		
Pump Housing, Fuel (34)			
Size (OD - 180° Sec)	24.0 in.	24.0 in.	24.0 in.
Material	Cast 347	Cast 347	Cast 347
Surface Finish	63/125	125/125	125/250
Tolerance			
Volute	±0.03	±0.03	±0.10
Contour	±0.003	±0.005	±0.100
Pilots	±0.001	±0.003	±0.005

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Quality Control	Current Aerospace	Current Aerospace	
Housing, Bearing Oxidizer (1)			
Size (OD)	5.9 in.	No Change	No Change
Material	347		
Surface Finish	32/63*		
Tolerance			
Pilot Diameters	±0.001		
Bearing Diameters	±0.0005		
Axial Dimensions	±0.001		
Quality Control	Current Aerospace		
Shaft, Oxidizer (2)			
Size (Bearing Diameter)	2.4 in.		
Material	Inconel X		
Tolerance			
Diameters	±0.0005	No Change	No Change
Axial Dimensions	±0.001		
Surface Finish	16/63		
Quality Control	Current Aerospace		
Dynamic Balance	Required		
Bearings, Oxidizer (3) (13)			
Size	60mm		
Number/Type	2/Preloaded Ball		

* Bearing Surface ID

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Material	440C/Armalon		
Class	5	No Change	No Change
Quality Control	Current Aerospace		
Seal Assembly, Bellows-Upper Oxidizer (4)			
Size (OD)	6.2 in.		
Material	347		
Tolerance			
Diameters	±0.001		
Flatness (Seal Surface)	1 Helium Light Band		
Type	Purged and Vented Dual Seal	No Change	No Change
Quality Control	Current Aerospace		
Axial Tolerance	±0.001		
Surface Finish (347 Material)	63		
Seal Ring, Running-Upper Oxidizer (5)			
Size (OD)	3.4 in.		
Material	347		
Surface Finish	63		
Seal Face (Flame Plated)	Ground and Lapped		
Diameters OD	±0.001	No Change	No Change
Diameters ID	±0.0005		
Axial Dimensions Tolerance	±0.001		
Quality Control	Current Aerospace		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Seal Ring, Running-Lower Oxidizer (6)			
Size (OD)	5.0 in.		
Material	347		
Surface Finish	63		
Seal Faces (2) (Flame Plated)	Ground and Lapped		
Tolerance		No Change	No Change
Diameter ID	± 0.0005		
Axial Dimension	± 0.001		
Squareness	0.0005		
Quality Control	Current Aerospace		
Seal Assembly, Shaft Riding Oxidizer (7)			
Size (OD)	6.6 in.		
Material	347		
Surface Finish	63		
Tolerance			
Diameter (OD)	± 0.001	No Change	No Change
Axial Dimensions	± 0.001		
Squareness	± 0.0005		
Quality Control	Current Aerospace		
Seal Assembly, Bellows-Lower Oxidizer (8)			
Size (OD)	6.6 in.		
Material	347		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Tolerance			
Diameters	± 0.001	No Change	No Change
Axial Dimensions	± 0.001		
Flatness (Seal Surface)	1 Helium Light Band		
Type	Purged and Vented Dual Seal		
Quality Control	Current Aerospace		
Surface Finish (347 Material)			
Nut, Seal Retaining, Oxidizer (9)			
Size (OD)	6.8 in.		
Material	Inconel X		
Tolerance			
Diameters (OD Thread)	Class A	No Change	No Change
(ID)	0.003		
Squareness	0.001		
Surface Finish	63		
Quality Control	Current Aerospace		
Filter, Oxidizer (10)			
Size (OD)	5.3 in.		
Rating	10 Micron		
Material	CRES 300		
Tolerance			
Diameter (OD)	0.030	No Change	No Change

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Diameter (ID)	0.001	No Change	No Change
Axial Dimensions	0.010		
Surface Finish (Machined Ends)	63		
Quality Control	Current Aerospace		
Spacer, Bearing, Oxidizer (12)			
Size (OD)	3.0 in.		
Material	Inconel X		
Tolerance			
Diameter (OD)	±0.005	No Change	No Change
Diameter (ID) (Pilot)	±0.0005		
Squareness	0.001		
Surface Finish	32 ID and Ends Only		
Quality Control	Current Aerospace		
Nut, Bearing Retaining, Oxidizer (14)			
Size (OD)	3.3 in.		
Material	A286		
Tolerance			
Diameter (OD)	±0.010	No Change	No Change
(ID) Thread	Class A		
Flatness	0.001		
Surface Finish	63		
Quality Control	Current Aerospace		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Seal, Labyrinth-Lower, Oxidizer (15)			
Size (OD)	12.0	No Change	No Change
Material	KEL-F		
Tolerance			
Diameter (OD)	±0.010		
(ID)	±0.002		
(Pilot)	±0.002		
Concentricity	0.002		
Quality Control	Current Aerospace		
Retainer, Labyrinth-Lower, Oxidizer (16)			
Size (OD)	12.8 in.		
Material	Aluminum		
Tolerance			
Diameter (OD)	±0.003		
(ID Pilot)	±0.002	No Change	No Change
Squareness	0.002		
Surface Finish	63		
Quality Control	Current Aerospace		
Volute, Pump, Oxidizer (17)			
Size (OD) (360° Section)	23 in.	23 in.	23 in.
Material	Cast Aluminum	Cast Aluminum	Cast Aluminum
Surface Finish	63/126	63/250	125/250

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Tolerances			
Flow Passage	±0.030	±0.10	±0.10
Pilot Diameters	±0.001	±0.001	±0.003
Axial Stack Up Dimensions	±0.003	±0.003	±0.010
Quality Control	Current Aerospace	Current Aerospace	Minimum
Nut, Volute Pump Retaining, Oxidizer (18)			
Size (OD)	5.8 in.		
Material	Inconel X		
Diameters (OD)	±0.010		
(ID Thread)	Class A	No Change	No Change
Squareness	±0.001		
Surface Finish	63		
Quality Control	Current Aerospace		
Impeller, Oxidizer (19)			
Size (OD)	13 in.	13 in.	13 in.
Material	Shell Mold-Cast Aluminum	Shell Mold-Cast Aluminum	Investment Cast Aluminum
Vane Tolerance	±0.025	±0.025	±0.010
Tip Tolerance	±0.010	±0.010	±0.010
Sealing Surface Tolerance	±0.002	±0.002	±0.005
Pilot Diameter Tolerance	±0.0005	±0.0005	±0.0005
Axial Stackup Tolerance	±0.010	±0.010	±0.010
Squareness	0.001	0.001	0.001

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Dynamic Balance	Required	Required	Required
Surface Finish	63	125	125
Quality Control	Current Aerospace	Current Aerospace	Minimum
Inducer, Oxidizer (20)			
Size (OD)	8.1 in.	8.1 in.	8.1 in.
Material	Forged Aluminum	Forged Aluminum	Die Cast Aluminum
Tolerance			
Vane	± 0.005	± 0.015	± 0.015
Daimeters (OD)	± 0.005	± 0.005	± 0.010
Pilots	± 0.0005	± 0.0005	± 0.0005
Axial Stack Up	± 0.010	± 0.010	± 0.010
Squareness	0.001	0.001	0.001
Dynamic Balance	Required	Required	Required
Surface Finish	63	125	125
Quality Control	Current Aerospace	Current Aerospace	Minimum
Bolt, Impeller Retaining, Oxidizer (21)			
Size (OD)	0.8 in.		
Material	K-Monel		
Tolerance			
Diameters - Pilot	± 0.001		
Thread	Class A	No Change	No Change
Other	± 0.010		
Squareness	± 0.001		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Quality Control	Current Aerospace		
Surface Finish	63		
Seal, Labyrinth-Upper, Oxidizer (22)			
Size (OD)	10.6 in.	No Change	No Change
Material	KEL-F		
Tolerance			
Diameter (OD)	±0.010		
(ID)	±0.002		
(Pilot)	±0.002		
Concentricity	0.002		
Quality Control	Current Aerospace		
Spacer, Seal-Labyrinth, Oxidizer (23)			
Size (OD)	11.7 in.	No Change	No Change
Material	Aluminum		
Tolerance			
Diameter (OD)	±0.010		
(Pilot)	±0.002		
(ID)	±0.005		
Surface Finish	63		
Quality Control	Current Aerospace		

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Retainer, Labyrinth-Upper, Oxidizer (24)			
Size (OD)	11.72 in.	No Change	No Change
Material	Aluminum		
Tolerance			
Diameter (OD)	±0.003		
(Pilots)	±0.002		
(ID)	±0.003		
Squareness	±0.001		
Surface Finish	63		
Quality Control	Current Aerospace		
Adapter, Pump Inlet, Oxidizer (25)			
Size (OD)	14.5 in.	No Change	No Change
Material	Cast Aluminum		
Tolerance			
Diameter (OD Pilots)	±0.002		
(OD)	±0.030		
(ID Bore)	±0.002		
(ID at Labyrinth)	±0.001		
Squareness (at Labyrinth)	0.001		
Surface Finish	63		
Quality Control	Current Aerospace		
Rotor, Turbine, Oxidizer (26)			
Size (OD)	19.5 in.	19.5 in.	19.5 in.

Subcomponent/Requirement	Base Value	Alternative No. 1	Alternative No. 2
Material (Forging)	Inconel 718	Inconel 718	Cast 718
Surface Finish	63	125	125
Tolerance			
Blades	±0.003	±0.010	±0.010
Diameters	±0.001	±0.001	±0.005
Quality Control	Current Aerospace	Current Aerospace	Minimum
Dynamic Balance	Required	Required	Required
Bolt, Rotor, Oxidizer (27)			
Quantity	6 ea.		
Size	3/8 dia x 1.85 long		
Material	A-286		
Tolerance	Class A Thread		
Diameter (OD)	±0.001	No Change	No Change
Surface Finish	32		
Quality Control	Current Aerospace		
Manifold, Turbine Inlet, Oxidizer (28)			
Size (Torus OD)	24.7 in.	24.7 in.	24.7 in.
Material (Cast. Formed and Welded)	Inconel 718	Inconel 718	CRES 347
Tolerance			
Diameters	±0.003	±0.003	±0.010
Vane Profiles	±0.003	±0.003	±0.010
Surface Finish, Vanes	63	125	250
Quality Control	Current Aerospace	Current Aerospace	Minimum

APPENDIX L

OPTIMAL TURBOPUMP REQUIREMENTS AND DESIGN CRITERIA

Appendix L

Subcomponent/Requirement	Optimum Value
Bearing Housing/Backplate, Fuel (1)	
Size (O.D.)	25.0 in.
Material	Cast 347
Surface Finish	125
Tolerance	
Pilot Diameters	± 0.003
Bearing Diameters	± 0.005
Axial Dimensions	± 0.003
1st Stage Turbine Rotor, Fuel (18)	
Size (O.D.)	10.8 in.
Material	Forged 718
Surface Finish	125
Tolerance	
Blade	± 0.010
Diameters and Axial Dimensions	± 0.005
Dynamic Balance	Require
2nd Stage Turbine Rotor, Fuel (19)	
Size (O.D.)	10.8 in.
Material	Forged 718
Surface Finish	250
Tolerance	
Blade	± 0.010
Diameters	± 0.010
Dynamic Balance	Required
Stator Vane, Fuel Turbine (21)	
Size (O.D.)	12.6 in.
Material	Inconel 718
Tolerance	
Vane Profile	± 0.005
Diameters	± 0.003
Surface Finish	125

Appendix L

Subcomponent/Requirement	Optimum Value
Pump Diffuser, Fuel (29)	
Size (Base Circle Dia.)	15.5
Material	Cast Aluminum (Machined)
Surface Finish	125
Vane Tolerance	± 0.003
Diameter Tolerance	± 0.003
Impeller, Fuel (30)	
Size (O.D.)	14.6 in.
Material	Forged Tungsten
Surface Finish	125
Vane Tolerance	± 0.005
Diameter Tolerance	± 0.005
Dynamic Balance	Required
Inducer, Fuel (31)	
Size (O.D.)	8.4 in.
Material	Forged Tungsten
Surface Finish	125
Vane Tolerance	± 0.005
Diameter Tolerance	± 0.005
Dynamic Balance	Required
Pump Housing, Fuel (34)	
Size (O.D. - 180° Sect)	24.0 in.
Material	Cast 347
Surface Finish	125/125
Tolerance	
Volute	± 0.03
Contour	± 0.005
Pilots	± 0.003

Appendix L

Subcomponent/Requirement	Optimum Value
Volute, Pump. Oxid. (17)	
Size (O.D.) (360° Section)	23 in.
Material	Cast Aluminum
Surface Finish	63/250
Tolerances	
Flow Passage	± 0.10
Pilot Diameters	± 0.001
Axial Stack Up Dimensions	± 0.003
Impeller, Oxid (19)	
Size (O.D.	13.0 in.
Material	Shell Mold Cast Aluminum
Vane Tolerance	± 0.025
Tip Tolerance	± 0.010
Sealing Surface Tolerance	± 0.002
Pilot Diameter Tolerance	± 0.0005
Axial Stackup Tolerance	± 0.010
Squareness	± 0.001
Dynamic Balance	Required
Surface Finish	125
Inducer, Oxid (20)	
Size (O.D.)	8.1 in.
Material	Forged Aluminum
Tolerance	
Vane	± 0.005
Diameters (O.D.)	± 0.005
Pilots	± 0.0005
Axial Stack Up	± 0.010
Squareness	0.001
Dynamic Balance	Required
Surface Finish	63

Appendix L

Subcomponent/Requirement	Optimum Value
Rotor, Turbine, Oxid (26)	
Size (O.D.)	19.5 in.
Material (Forging)	Inconel 718
Surface Finish	125
Tolerance	
Blades	$\pm$ 0.010
Diameters	$\pm$ 0.001
Dynamic Balance	Required
Manifold, Turbine Inlet, Oxid (28)	
Size (Torus O.D.)	24.7 in.
Material (Cast. Formed & Welded)	Inconel 718
Tolerance	
Diameters	$\pm$ 0.003
Vane Profiles	$\pm$ 0.003
Surface Finish, Vanes	125

All Other Fuel and Oxidizer Turbopump Component Requirements Constant at Base Case Values

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